4.4.4 Rock and soil properties

Laboratory tests were made in the central laboratory of GSE to identify the rock and soil properties of the drilling core physically and chemically. The laboratory test is composed of sieve analysis, pipette analysis, bulk density, specific gravity and X-ray diffraction (hereinafter XRD). The implemented tests and their depth of cores are shown in Table 4.4.3. The detail results of the laboratory tests are shown in Appendix.

Table 4.4.3 Implemented laboratory tests

Drilling No.	Depth (m)	Bulk density	Pipette	Sieve	Specific gravity	XRD
B05-11	12.30～12.50	○				
	22.50～22.70	○				
B05-12	15.70～15.90		○	○	○	○
	25.00～25.25	○				
	30.45～30.55	○				
B05-21	19.10～19.25	○				
	29.10～29.25	○				
	34.15～34.25		○	○	○	○
B05-22	12.50～12.65	○				
	24.75～25.00	○				
	28.15～25.30		○	○	○	○
B05-31	10.40～10.60	○				
	25.10～25.30	○				
B05-32	8.10～ 8.30	○				
	22.70～22.90	○				
B22-11	18.60～18.75	○				
B27-11	18.40～18.50	○				
B27-12	20.45～20.55	○				
B27-21	15.05～15.20	○				
B27-22	19.65～19.80	○				
B27-23	10.10～10.25					○
	22.10～22.20					○
B28-11	6.20～ 6.35	○				
	18.50～18.65	○				
B28-21	15.25～15.40	○				
	22.00～22.15	○				
B28-31	13.20～13.50	○				
	21.00～21.15	○				
B28-32	33.60～33.75	○				

a. Bulk density test

The results of the bulk density tests, included water absorption and porosity, are summarized in the Table 4.4.4. The table indicates the average values from two samples of each core.

Rock and soil are generally composed of silicate minerals, calcareous matters and organic matters etc. The density of general silicate minerals and calcareous matters is 2.5-2.8 g/cm^3 while the density of organic matters is 1.4-2.4 g/cm^3. The bulk densities of the rocks and soils in the area are around 2.2-3.0 g/cm^3, therefore, it is considered to be rich for silicate and calcareous minerals and less organic matters.

Table 4.4.4 The results of the bulk density tests

Drilling No.	Depth (m)	Geology	Water absorption (%)	Porosity (%)	Bulk density (g/cm3)
B05-11	12.30～12.50	limestone	1.51	3.90	2.59
	22.50～22.70	limestone	4.41	10.56	2.40
B05-12	25.00～25.25	limestone	1.17	3.01	2.57
	30.45～30.55	limestone	4.16	10.00	2.40
B05-21	19.10～19.25	limestone	5.08	11.80	2.32
	29.10～29.25	limestone	1.35	3.50	2.60
B05-22	12.50～12.65	limestone	2.62	6.49	2.49
	24.75～25.00	limestone	3.01	7.51	2.49
B05-31	10.40～10.60	limestone	1.44	3.69	2.56
	25.10～25.30	limestone	1.14	2.97	2.60
B05-32	8.10～ 8.30	limestone	0.23	0.60	2.67
	22.70～22.90	limestone	2.61	6.58	2.52
B22-11	18.60～18.75	sandstone	6.24	13.98	2.24
B27-11	18.40～18.50	shale			2.30
B27-12	20.45～20.55	tuff			2.20
B27-21	15.05～15.20	silt			2.16
B27-22	19.65～19.80	silt			2.22
B28-11	6.20～ 6.35	basalt gravel			3.03
	18.50～18.65	silt			2.32
B28-21	15.25～15.40	limestone	3.39	8.31	2.45
	22.00～22.15	tuff	0.41	1.16	2.88
B28-31	13.20～13.50	sandy gravel	0.27	0.77	2.91
	21.00～21.15	basalt gravel	1.31	3.36	2.58
B28-32	33.60～33.75	tuff			2.33

b. Grain size analysis

The results of the grain size analysis, which is the sieve analysis and pipette analysis, and specific gravity in limestone of B05-12, B05-21 and B05-22 are summarized in the Figure 4.4.22.

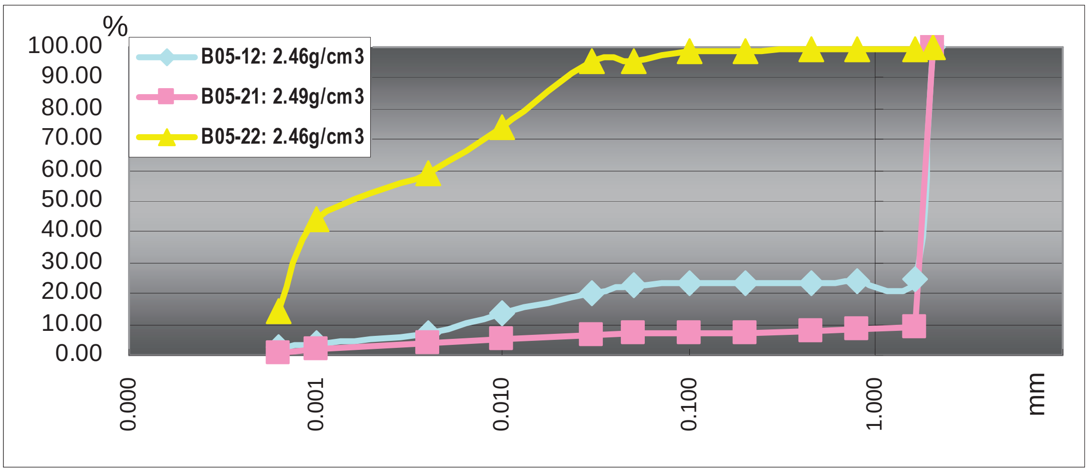


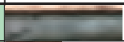
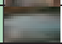
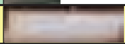
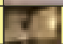
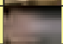
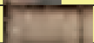
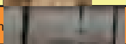
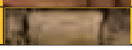
Figure 4.4.22 Cumulative distribution of grain size analysis

The limestone of B05-12 and B05-21 are well grained at around coarse sand to fine gravel, which means that the grain size is highly concentrated at 1.0-2.0mm. The limestone of B05-22 mainly consists of finely-divided particles less than 0.04mm

c. XRD

According to the results of XRD, the limestone in the L/S05 area majorly consists of quarts and calcite, on the other hand, the sliding soil mass which is weathered silt in the L/S27 area majorly consists of quarts, muscovite and albite. The results of XRD are summarized in the Table 4.4.5

Table 4.4.5 The results of XRD

distinct	borehole number	sample number	depth(m)	geology	core photo	Pillar-shaped chart description	kind of mineral																notes
							Quartz	Quartz alpha	Muscovite	Dolomite	Calcite	Calcite magnesian	Albite	Albite high	Albite low	Microcline	Vermiculite	Kaolinite	Sepolite	Dickite	Cebalite	Tridymite	
L/S00	B00-14	a	27.6-27.8	tuffaceous mud/medium tuff		Cylinder shape core											○						Vermiculite or Dickite is rich
		b	28.9-29.0	tuffaceous mud/medium tuff			24.4													75.6			
		c	29.9-30.0	tuffaceous mud/medium tuff													○						
	B05-12		15.7-15.9	limestone		Cylinder shape core	52.9				10.1							37.1					Quartz,Calcite is rich partially contained Muscovite clay mineral is Kaolinite
	B05-13		30.9-31.0	limestone		crushed core	95.7				4.3												
	B05-21		34.15-34.25	limestone		crack	51.0				49.0												
	B05-22		28.15-28.3	limestone		rubble core contain clay		32.2	33.8		34.0												
	B05-23		31.7-31.85	limestone		weakly crushed core	49.6					50.4											
L/S27	B27-09	a	26.3-26.5	shale-silte alternation		crack	80.2						17.6						2.2				Quartz,Albite is rich partially contained Muscovite, Tridymite
	B27-10	a	15.6-15.8	shale-silte alternation		Crushed core(surroundings)	75.9			4.2	3.3		16.6										
	B27-23	a	10.1-10.25	siltstone&shale		crack	46.8								46.1						7.1		
									42.9						38.9							18.2	
		b	22.1-22.20	siltstone&shale		crack	8.3							17.3						2.4			
	B28-13	a	11.5-11.7	colluvial deposit		weathered	29.7		63.5							6.7							Quartz, Muscovite is rich
		b	25.7-25.9	colluvial deposit		weathered	71.8		25.1		3.1												

Figures in the table indicate percentage (%)

From the result of XRD analyzing of borehole cores in various areas, we can know the following features on the mineral composition of the stratum.

1) The tuffaceous mud and medium tuff layer in L/S00 area contains a lot of vermiculite or dickite.

2) The limestone layer in L/S05 area contains a lot of Quartz and Calcite, and it also contains some muscovite and clay mineral kaolinite.

3) The shale and the siltstone alternation of strata in L/S27 area contain a lot of quartz and albite, and also contain some muscovite and tridymite.

4) Colluvial deposit layer in L/S28 area contains a lot of quartz and muscovite.

4.4.5 Discussions on the slip surface

a. Methodology of landslide analysis

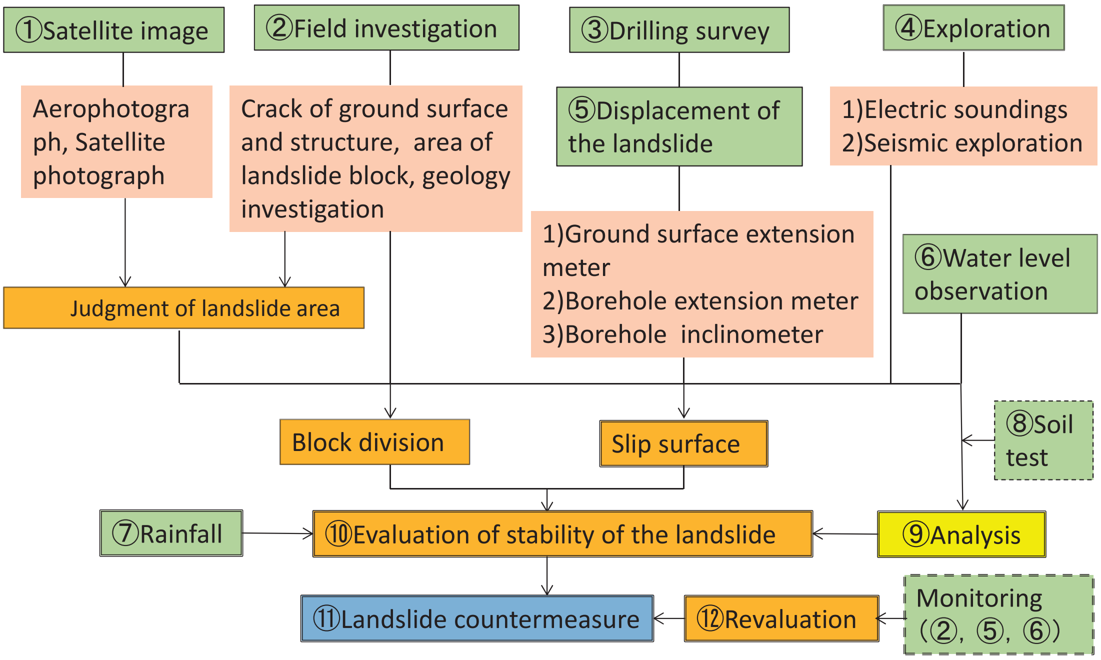


Figure 4.4.23 Flow of landslide survey and landslide analysis

Figure 4.4.23 shows general flow of the landslide item and analysis.

1) ① is acquisition of the satellite image, and ② is field investigation. Judgment of landslide area and rough block division are executed from these results.

2) ③ is the drilling survey, and ④ is the exploration. The drilling survey is a survey of the point, and the exploration is a survey of the line.

3) Investigation of the displacement (⑤) of the landslide blocks and water level observation (⑥) are executed using boreholes.

4) Landslide block and the slip surface are identified by detailed field investigation, the drilling survey, geophysical exploration, monitoring of the displacement of the landslide, water level observation.

5) The stability analysis is executed with parameters estimated by back analysis (or soil strength obtained from the soil test if possible).

6) The landslide measures works ate planned based on this result of the survey, and a part of them is executed.

7) The stability of the landslide is revalued from the movement observation of the field investigation, investigation of the displacement of the landslide, and the observation of water level.

The landslide blocks and cross sections of the slip surface made by the results of the geomorphological and geological analysis, the site reconnaissance, and the monitoring are used for the slip surface analysis. Based on the sampling data of the borehole core, it is considered that the geological boundary and heavily weathered and/or clayey thin layer are the slip surfaces. The landslide block activities are estimated by extensometers, which observe displacement corresponding to rainfall. The monitoring data of the borehole inclinometer is used for the depth of the slip surface and displacement of the landslide mass.

The monitoring data of the water level meter is utilized for the analysis the groundwater level. However, the results obtained for each borehole were different from the altitude of the spring water at the site. P wave velocity and specific electrical resistivity as keys at the borehole point in seismic exploration and electric sounding is used for check of the stratum spread and the existence of a water channel in the ground.

b. Slip surface on each site

The landslide blocks and slip surface were examined by other information regarding surface anomalies on the road and locations of spring water by hearing survey form the residents and site reconnaissance. Hereinafter, the characteristics of the movements of the landslide block and determined the tentative slip surface will be described as follows.

The Abay area is divided three types with the geological feature of landslide (Figure 4.4.24).

Landslide area I: this area is characterized by alternative layer of the basaltic lava and the pyroclastic rocks. The landslides are almost triggered by the pyroclastic material.

Landslide area II: this area is characterized by the limestone and the intercalated siltstone and shale. The intercalated siltstone and shale can be slip surface.

Landslide area III: this area is characterized by the lower shale, which also make a gentle slope as a result of landslide movements.

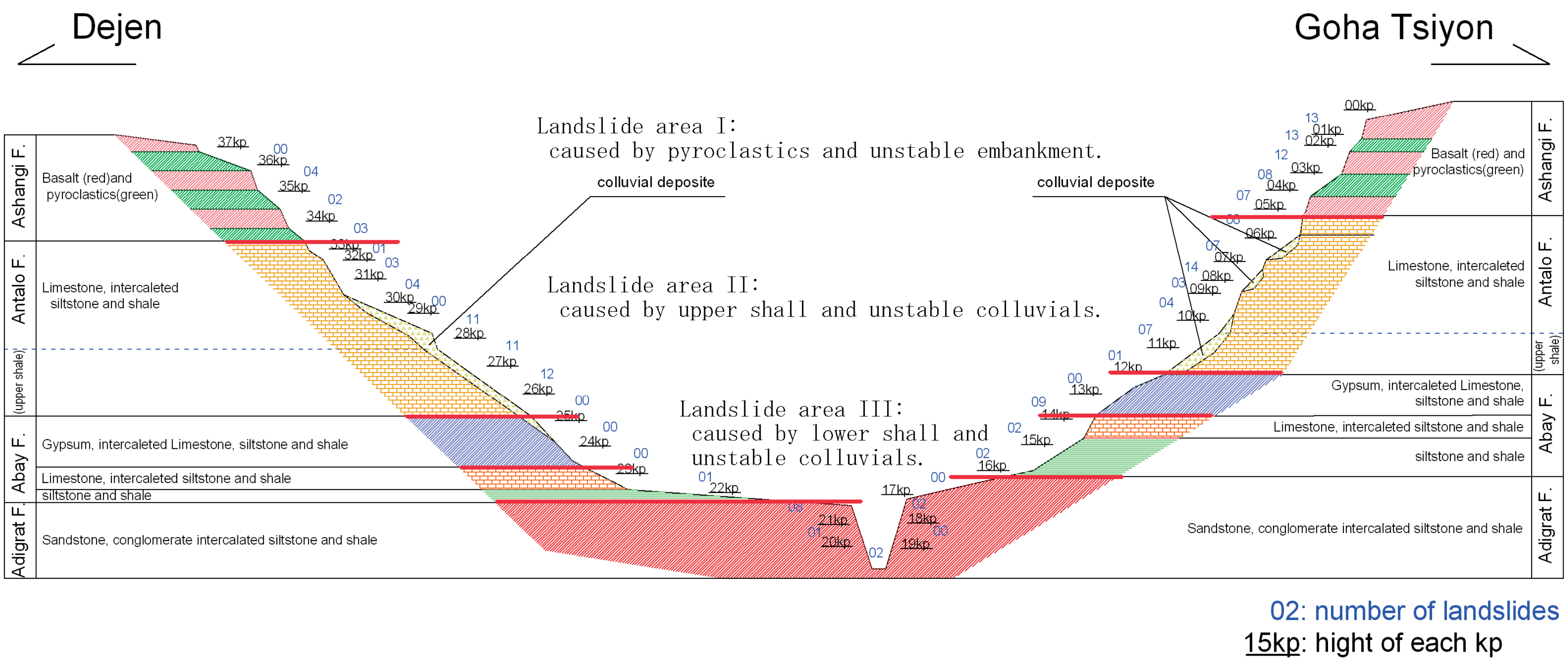


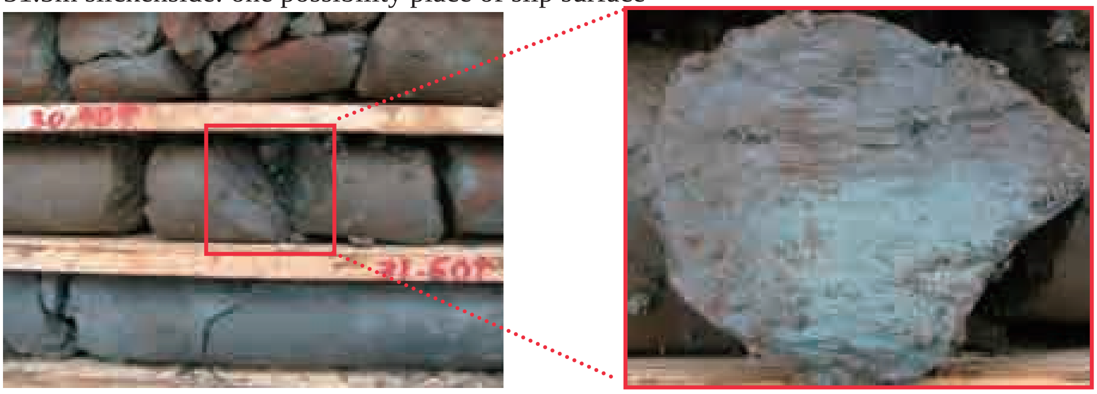
Figure 4.4.24 Geological schematic section of Landslide area subdivision

b.1 L/S00

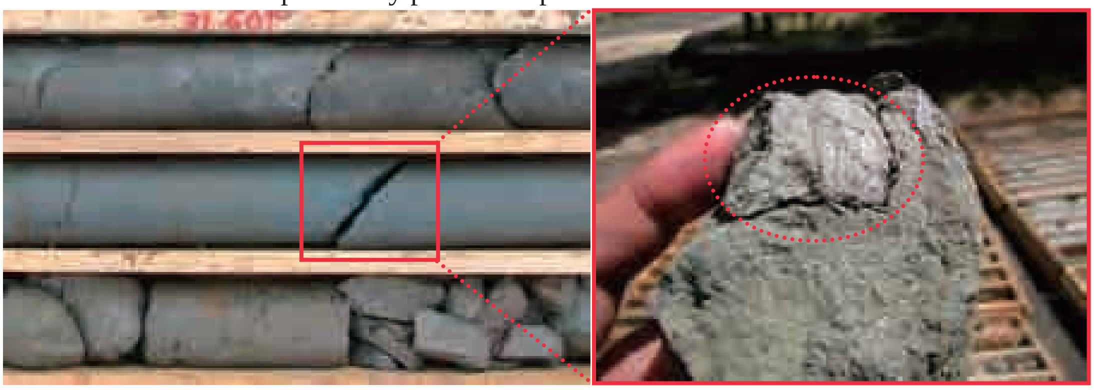
The L/S00 belongs to the Landslide area I. This area is composed of 12 landslide blocks. Block 00-08 is the major landslide block that directly damaged the road continues to these days.

Before discussion for slip surface in the area, the assumed slip surface or slickenside in the core on the drilling survey should be confirmed as the following pictures.

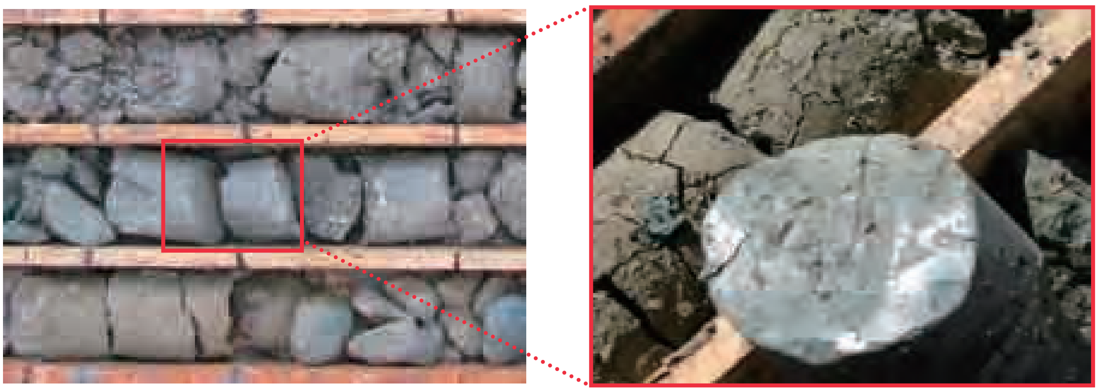
B00-12:
31.5m slickenside: one possibility place of slip surface



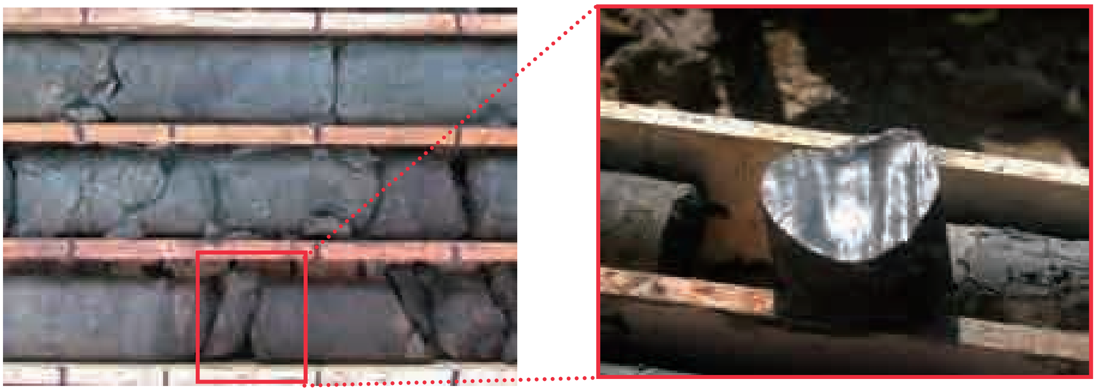
33.7m slickenside: one possibility place of slip surface



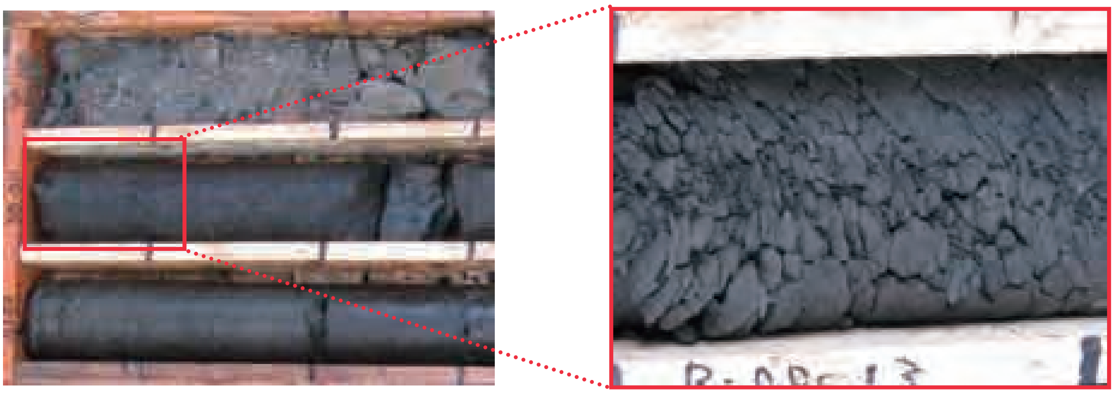
B00-13:
28.3m slickenside: one possibility place of slip surface



34.45m slickenside: one possibility place of slip surface



Around 36.0m mudstone: This type of mudstone is very weak to dehydration. These cores (deeper than 36.0m) are taken out as a column-shape. The left photograph was taken at 4 days later after the drilling out. It is easy to deform by pushing with finger.



B00-13:
24.7m slickenside: one possibility place of slip surface

25.5m slickenside: one possibility place of slip surface

In view of the landslide situation, block 00-08 is assumed to be a “complex slide”. The scarp zone is at the eastern end of the road, and the end zone is in the terrace located east-southeast of the road. Depression zone formed as a result of the horizontal movement of the soil mass in the middle slope. The block is assumed to have moved from the embankment of the road, due to the rising of the ground water level in the rainy season from 2009 to 2011. The extrusion is observed at the end zone. New cracks occurred in this extrusion, and landslide blocks 00-07, 00-10, and 00-11 are assumed to have been triggered by this extrusion. In view of the cracks on the ground surface, block 00-07 is divided into smaller blocks.

Spring water was observed at three points through the all season of 2010 and 2011: just above the slope of the road (altitude 2,390m), at the slope toe of the embankment (altitude 2,365m), and near the scarp zone of block 00-06 (altitude 2,375m). The spring water level is analyzed to draw the landslide cross section in Figure 4.4.25. The ground water level in B00-21 is different from the altitude of spring water at the site. Therefore, the observed data of ground water in B00-21 is not adopted for stability analysis. Monitoring for ground water during the next rainy season is needed.

Multi-tuff layers existed at 27.8 to 28.4m depth and 31.5m depth for B00-12, and a multi-tuff layer or a clay layer existed in another borehole. A tuff layer existed on the line connected at 25m depth in the embankment and 15m depth in the middle to lower slope. It is assumed that the tuff layer forms the slip surface because the layer has low shear strength. It is possible that the tuff layer expands to the upper slope and develops into a potentially large landslide. Continued investigation is required for confirmation.

Displacement of block 00-08 was detected at a depth of 17.0m depth by a borehole inclinometer in 2010. This displacement is assumed to have occurred at the inner embankment of the road; however, it could also extend to the entire block 00-08.

In consideration of above mentioned results of the investigation and the monitoring, slip surfaces were discussed. The thick red line in Figure 4.4.25 denotes the possibility of the slip surface. Slip surface (1) is a landslide of the embankment which is the smallest volume in the area; slip surface (2) is a landslide continuing from the road to the end of the field plane; and slip surface (3), which is few possible but 31.5m and 33.7m depth have former clear slickenside at borehole B00-12, is a landslide continuing form the upper part of the basalt slope to the end of the field plane.

In July 2011, borehole B00-14 was excavated for investigation, and groundwater level monitoring is conducted in this borehole. During the rainy season, the groundwater level in this borehole stayed around 22.5-23.5m, although some new cracks were generated along the road. There is no evidence showing groundwater level increasing. It was observed during the field reconnaissance that a line of springs distributed along the same elevation in the two side slopes of the road. It is estimated that a water vein may be formed along the cracks in the basalt layer. In August 2011, small scale failure and rockfall occurred on the slopes above the road. These slopes are weak and unstable, and in the next rainy season, small scale failure and rockfalls will occur again in the same slopes.

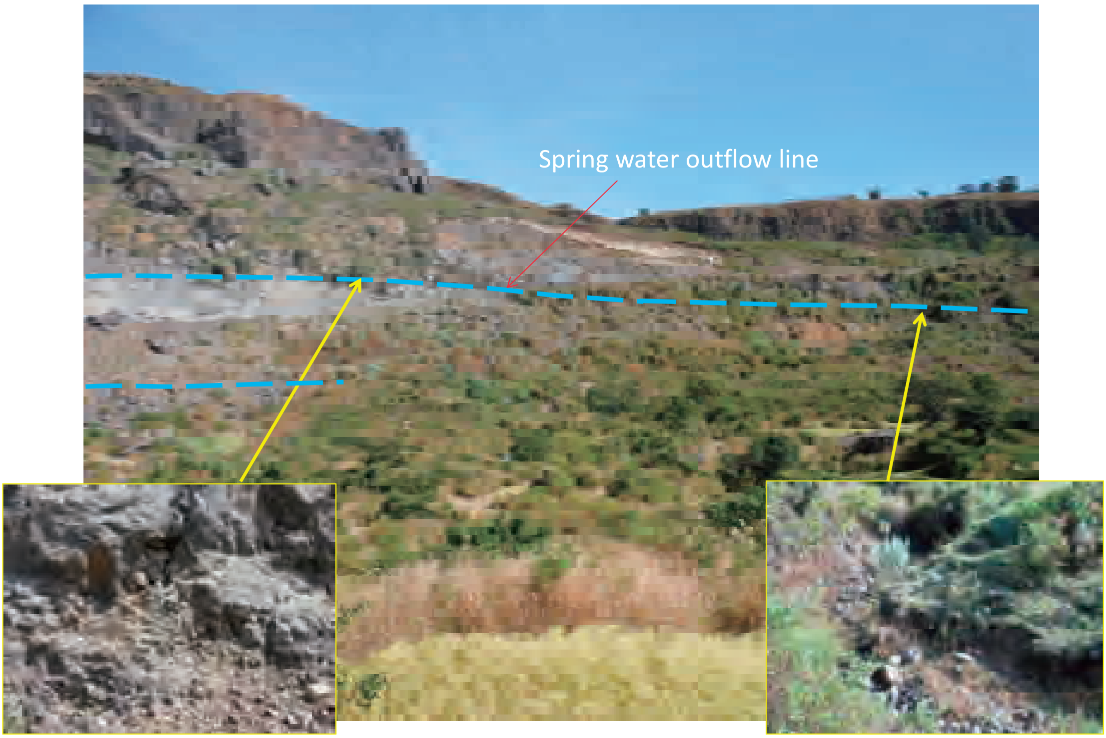


Photo 4.4.30 Spring water outflow line in L/S00 area

Table 4.4.6 summarizes the investigation and monitoring data for the L/S00 area. The detailed conditions of the monitoring by the equipment are described in the previous chapter 4.4.3.

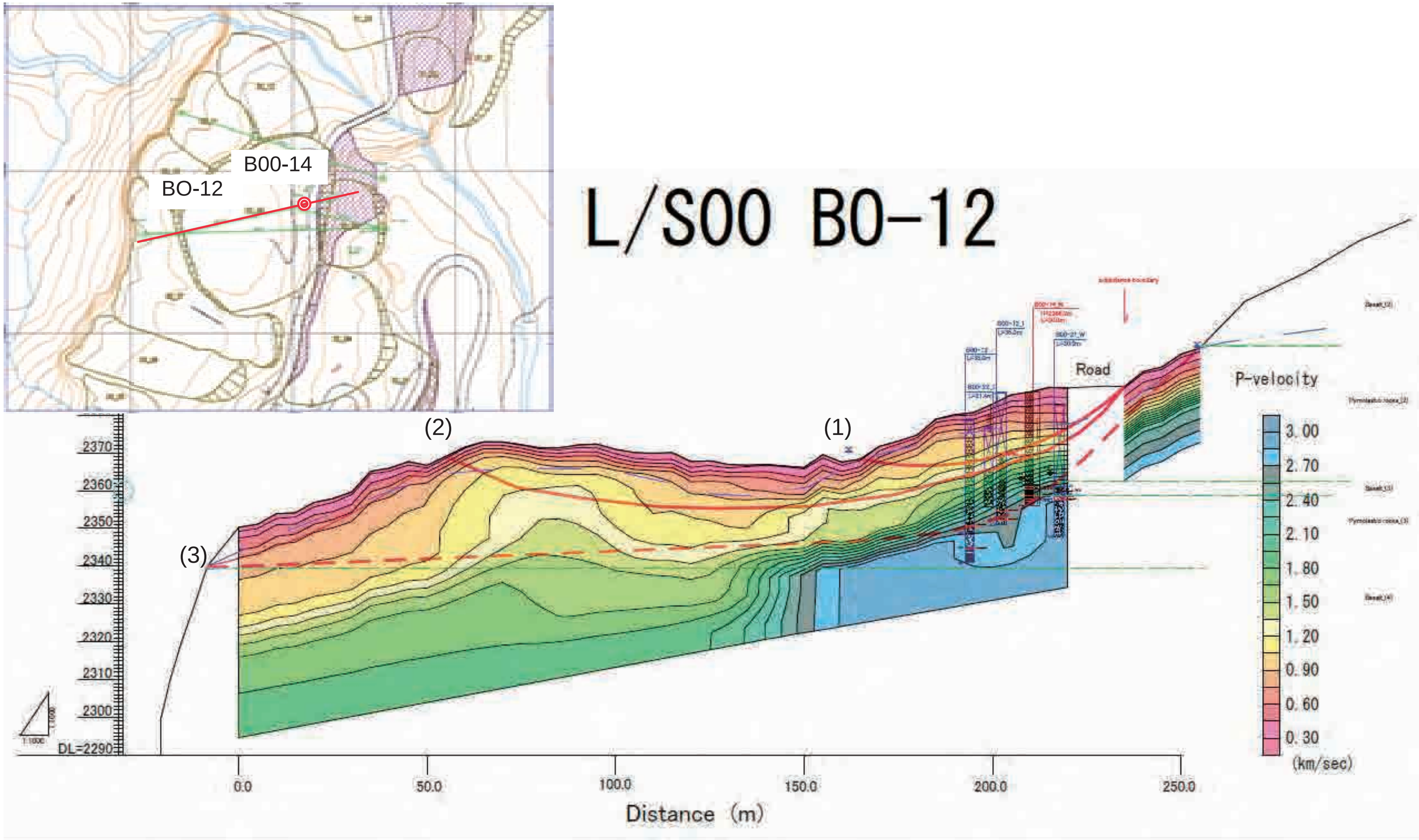


Figure 4.4.25 Landslide cross section of L/S00

Table 4.4.6 Investigation and observation data of L/S00-08 landslide block in the L/S00

Clarity of crack	Drilling survey		Extensometer		
	Borehole number	**Depth of slip surface**	**Equipment number**	**Setting day**	**variation**
00-00: crack of ground surface 00-10,00-11: collapse topography, expansion of crack of scarp zone and side wall zone 00-08: existence of sink zone, rising of end zone 00-07: existence of sink zone, crack of scarp zone and side wall zone (continuity)	B00-11		EX-1	24 Jun.	42.4mm(compression26.6mm) Until 15th Jun, 2011 17th May.to8th Oct,2011: 23.4mm tension
	B00-12	27.8-28.4m:tuff 31.5m:slip surface in deep layer			
	B00-13	23.5-25.3m:tuff			
	B00-21	24.7m:tuff			
	B00-22	10.5m,16.7-16.8m, 20.2-20.4m:clay			

Borehole extensometer			Borehole inclinometer			Water level meter		
Equipment number	**Installation day**	**variation**	**Equipment number**	**Installation day**	**Variation**	**Equipment number**	**Installation day**	**Variation**
B00-11	1 August	0.1mm Until 16th Jun,11	B00-12	26 July	17.0m 12 Aug., immeasurable at 16.2m	B00-21	3 Aug.	Steady water level -20 to -23m Maximum water level -18.1m (9/14)
			B00-22	19 October	10.5m	B00-14	1 Aug.,2011	-22.728mto-23.595m

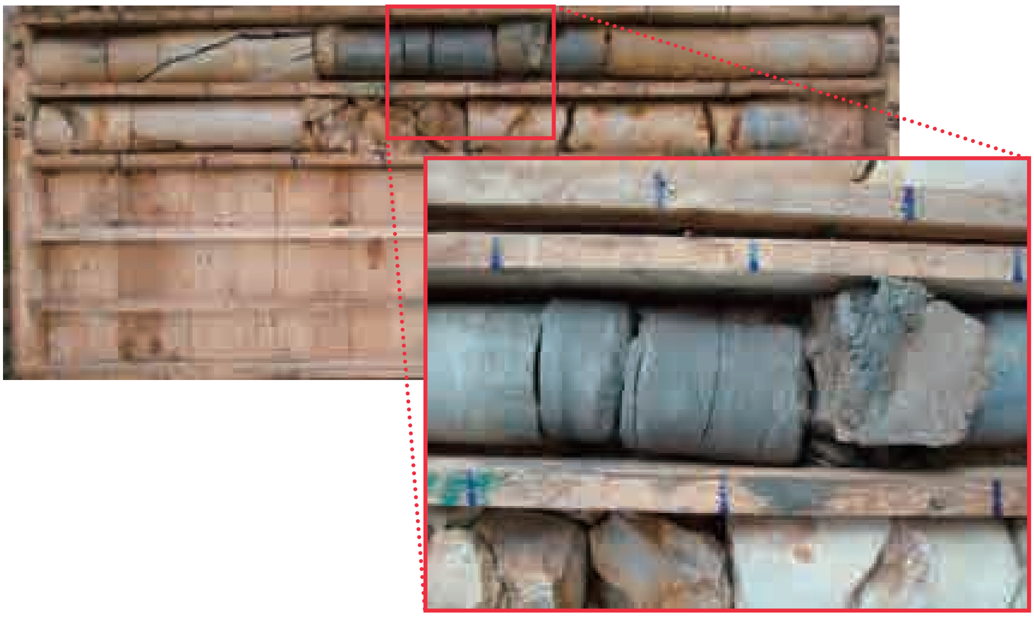
Seismic exploration / Velocity classification	Electric sounding / Specific resistance classification
First layer (embankment, colluvial deposit, pyroclastic):-0.8km/s Second layer(colluvial deposit, basalt):0.8-1.4km/s Third layer(basalt, pyroclastic):1.4-2.5km/s	

b.2 L/S05 area

The L/S05 belongs to the Landslide area I and II. This area is composed of 8 landslide blocks. Block 05-01 and 05-02 are the major landslide block that directly damaged the road continues to these days. Block 05-01 is colluvial landslide on the Landslide area I, and Block 05-02 is on the Landslide area II.

Before discussion for slip surface in the area, the assumed slip surface or slickenside in the core on the drilling survey should be confirmed as the following pictures.

B05-12 (block 05-02)
30.30-30.65m: cohesive soil. This place is one possibility place of slip surface, but it had no slickenside.



B05-13 (block 05-02)
Mudstone layer intercalate at 31.50m depth: This place is one possibility place of slip surface, but it had no slickenside and no intercalated clay.

B05-23 (block 05-02)
30.93m – 31.05m slickenside: one possibility place of slip surface

Two roads exist in the landslide area. The cracks on the ground surface and retaining walls of the road due to the landslide suggest that the block is divided into an upper block (block 05-01) and a lower block (block 05-02). In the upper block, the scarp zone is just below the terrace of the upper slope, and the end zone is the slope shoulder of the upper road. In the lower block, the scarp zone is located on the lower road, and a new crack is observed on the road. The block 05-07 is treated as an independent block that is subdivided block 05-02.

Spring water is observed at two points during the rainy season of 2010: just above the slope of the upper road (altitude 2,140m) and the lower slope of the lower road (altitude 2,080m). Also, spring water is observed at the mountainous side of the slope in the dry season. The spring water level analyzed to draw the landslide cross section in Figure 4.4.26. The water levels in B05-12 and B05-31 are different from the altitude of spring water at the site. Therefore, the observation data of water level is not adopted for the stability analysis. Monitoring for the ground water during the next rainy season is needed.

The upper block (i.e., block 05-01) is a slide of colluvial deposit and pyroclastic material, located in the upper level of the limestone. However, no slip surface has been detected. Continued investigation is required for confirmation.

Displacement is observed at depths of 6.6m depth for B05-21 and 11.6m depth for B05-22 using a borehole inclinometer; this result indicates that the lower block is an active landslide. Multi-tuffaceous siltstone layers are confirmed in the limestone layer. Currently actualized landslides may develop into a large landslide, including an upper block and a lower block. Continued investigation is required for confirmation.

In consideration of above mentioned results of the investigation and the monitoring, slip surfaces were discussed. The thick red line in Figure 4.4.26 denotes the possibility of the slip surface. Slip surface (1) is a landslide of colluvial deposit and pyroclastic material on the upper slope and there are several possibilities for potential slip surface; slip surface (2) is a landslide continuing form the lower slope to the field area.

In July 2011, borehole investigation was conducted in borehole B05-13 and B05-23. Borehole B05-13 was also used for groundwater monitoring and inclinometer monitoring, while borehole B05-23 was used for inclinometer monitoring. The groundwater level in borehole B05-13 is 35-40m deep, which is below the slip surface. The inclinometer monitoring result indicates that the accumulated displacement at 12.5m deep in borehole

B05-13, while similar displacement was indicated by the result at 3.5m and 17.5m in borehole B05-23. In the lower block, the slip surface is located at the bottom of the colluvial deposit, or in the strongly weathered limestone. In the upper block, there is deformation detected with the extensometers No.2 and No.3 which were set up at the gentle place, and there is no obvious deformation in the underground extensometer installed in borehole B05-11. However, the displaced debris reached the height of the extensometer pipe set at the slope surface.

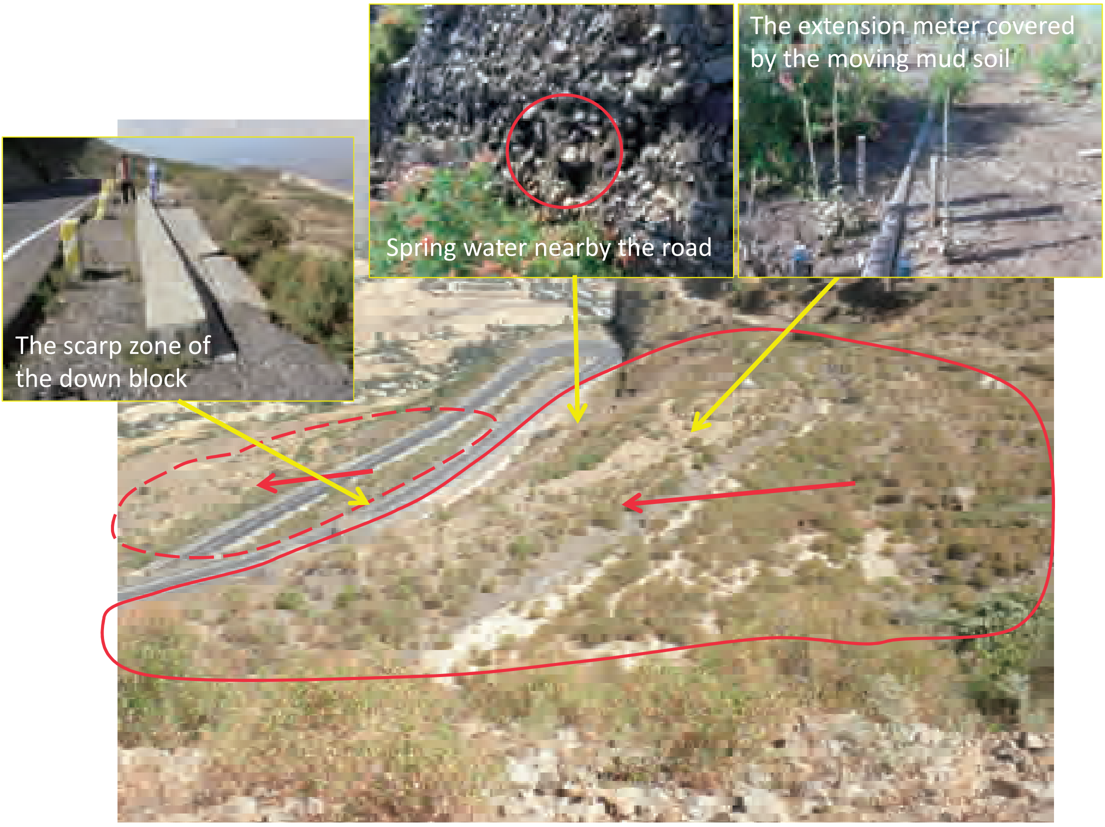


Photo 4.4.31 Landslide situation in L/S05 area

Table 4.4.7 summarizes the investigation and monitoring data for the L/S05 area. The detailed conditions of the monitoring by the equipment are described in the previous chapter 4.4.3.

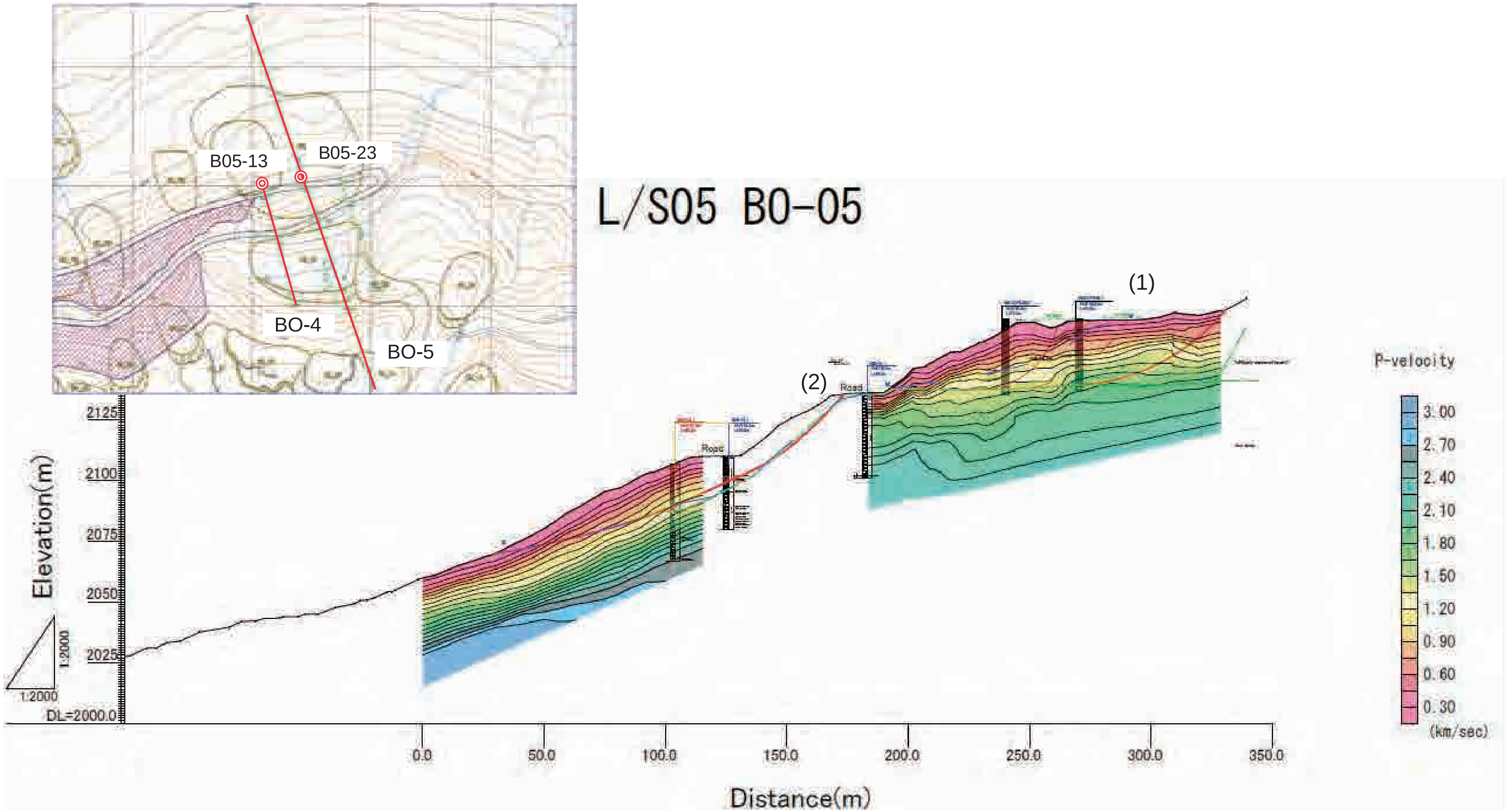


Figure 4.4.26 Landslide cross section of L/S05

Table 4.4.7 Investigation and observation data of L/S05-01 landslide block in the L/S05

Clarity of crack	Drilling survey		Extensometer		
	Borehole number	Depth of slip surface	Equipment number	Installation day	Variation
05-01:existence of sink zone, spring water abundance 05-05, 05-06:crack of scarp zone on the road	B05-11	2.5m: stratum boundary (bedrock: limestone)	EX-2	24 June	7th Oct.,2011:42.5mm extension
	B05-12	10.8m:stratum boundary (bedrock: limestone), slip surface	EX-3	24 June	15th Sep.,2011:56.4mm extension
	B05-13	Under investigation.			
	B05-21	10.7-10.8m, 30.7-30.9m, 33.7-34.0m:tuff			
	B05-22	10.8m:stratum boundary (bedrock: limestone), slip surface 21.3-21.9m, 23.7-24.3m, 25.3-25.7m, 27.3-27.7m, 28.0-28.4m:tuff			
	B05-23	Under investigation. 30.94-31.05m: tuff (slip surface)			
	B05-31	0.5m:stratum boundary (bedrock: limestone), slip surface			
	B05-32	7.25m:stratum boundary (bedrock: limestone), slip surface			

Borehole extensometer			Borehole inclinometer			Water level meter		
Equipment number	Installation day	Variation	Equipment number	Installation day	Variation	Equipment number	Installation day	Variation
B05-11	14 Aug.	15 Jun.2011 7.1mm extension	B05-21	4 Aug.	6.6m Near 30.8m tiny displacement	B05-12	14 Aug.	Steady water level -31 to -32m Maximum water level -31.0m (15 Aug.)
		8 Oct.,2011 7.5mm extension	B05-22	9 Sep.	Near 11.6m, 28m tiny displacement (?)	B05-31	1 Sep.	Steady water level -22 to -23m Maximum water level -22.2m (9 Oct.)
			B05-13	July.	12.5m clear displacement	B05-13	7 July.	11 July.to7 Oct.:-34.976 to -40.000m
			B05-23	Aug.	3.5,17.5m clear displacement			

	Seismic exploration/Velocity classification	Electric sounding / Specific resistance classification
1) Upper slope:	First layer (colluvial deposit, pyroclastic):-0.6km/s Second layer (limestone):0.6-1.4km/s Third layer (basalt, pyroclastic):1.6-3.0km/s	First layer (colluvial deposit, pyroclastic):50-75Ωm or 30-50Ωm Second layer (limestone):10-45Ωm or 50-75Ωm
2) Middle slope:	First layer (colluvial deposit, pyroclastic):-0.5km/s Second layer (limestone):0.5-0.7km/s Third layer (basalt, pyroclastic):0.7-1.0km/s	First layer (colluvial deposit, pyroclastic):50-70Ωm Second layer (limestone):30-50Ωm
3) Lower slope:	First layer (colluvial deposit, pyroclastic):-0.6km/s Second layer (limestone):0.6-1.9km/s Third layer (basalt, pyroclastic):1.9-4.0km/s	First layer (colluvial deposit、pyroclastic):10-30Ωm Second layer (limestone):30-50Ωm

b.3 L/S22 area

The L/S22 belongs to the Landslide area III. Two active blocks exist in the L/S22 area. Block L/S22-1 is adjacent to the road, and its displacement is large. The crack of the scarp zone has expanded and extends close to the road shoulder.

Spring water is observed at the end of sliding mass from opposite side of the cliff in the rainy season. Ground water infiltrates into the landslide in the rainy season; as a result, the soil mass moves toward the valley. The bedrock is sandstone. As the weathering of the sandstone in this area progresses, the soil mass collapses at the end zone. Although no activity was observed in the moving layer during the Project period, cracks have developed on the surface.

Photo 4.4.32 Landslide 22-01 from opposite side terrace cliff.

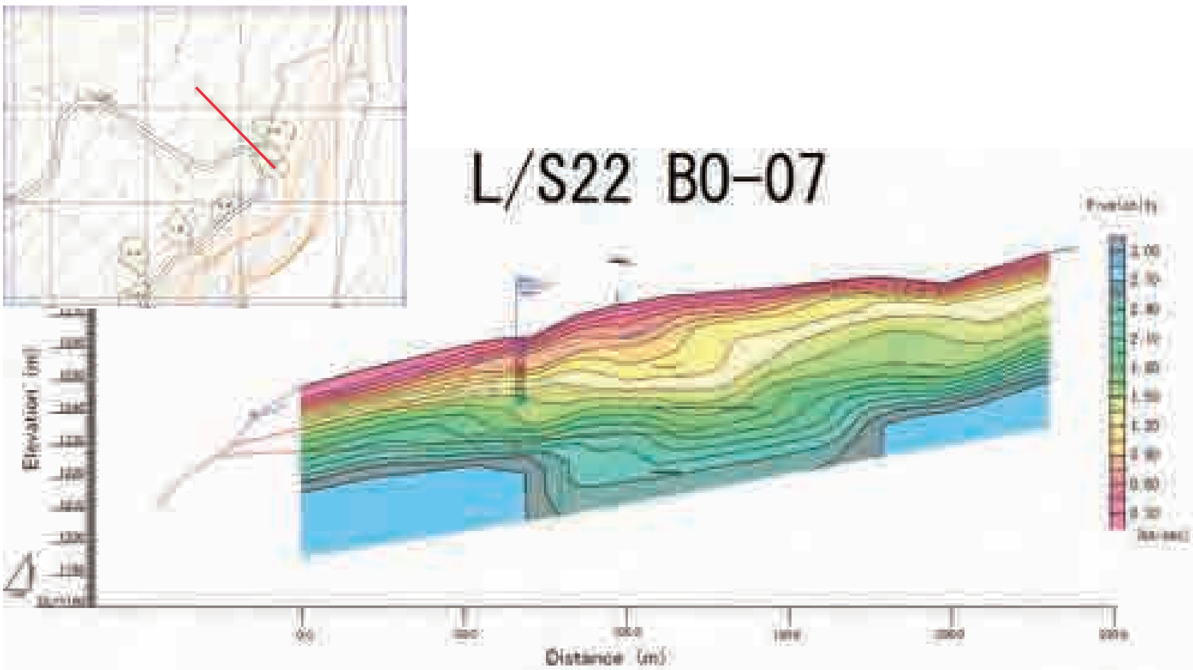


Figure 4.4.27 Landslide cross section of L/S22

b.4 L/S27 area

The L/S27 belongs to the Landslide area II. In this area, the landslide block continues from the upper slope to the lower slope. The road has a hairpin curve in this area. The landslide movement is remarkable along the cross section line. Landslide anomalies such as new cracks extending to extensometer EX-4, cracks in the right side wall of the road, continues cracks nearby the church, and cracks in the scarp zone in lower block containing the road shoulder can be found along the cross section line.

Two blocks damaged the road along the cross section line. In the upper block 28-01, the scarp zone of the landslide has cracks that continue to extensometer EX-4, and the end of the landslide is the lower road. In blocks 27-04, the scarp zone of the landslide is the lower road shoulder, which crosses over to the end zone of the upper block.

Block 28-01 is assumed to be a slide of colluvial deposit containing mainly basalt, and the matrix is siltstone and shale. The thin tuff layer is assumed to be the slip surface of the valley side wall of block 28-01 in the outcrop.

Spring water is observed at two points in the rainy season of 2010: the upper slope near the scarp zone (altitude 1,765m) and the slope (altitude 1,715m) just below the road. This spring water is assumed to continue to the depression zone on the left side. The spring water in the valley side slope is observed in the dry season. The spring water level is analyzed by the landslide cross section in Figure 4.4.28. The water levels in B27-21 and B27-23 are different from spring water at the site. Therefore, the observed water level is not adopted for the stability analysis. Monitoring for the water level during the next rainy season is needed.

Borehole bending is at 7.5m depth for B27-21 and accumulated extension displacement using a borehole inclinometer at 15.0m depth for B27-22. Additional borehole surveys and continued investigation is required for confirmation.

In consideration of above mentioned results of the investigation and the monitoring, slip surfaces were discussed. The thick red line in Figure 4.4.28 denotes the possibility of the slip surface. Slip surface (1) is a landslide of colluvial deposit near the road and the settlement; slip surface (2) is a large landslide form the upper slope to the lower road; and slip surface (3) is a landslide of the lower field area.

In 2011, borehole investigation was conducted at B27-09 and B27-10 along the BO-08 measure line. In B27-09, groundwater level monitoring and inclinometer monitoring is conducted; while in B27-10, inclinometer monitoring is conducted. The groundwater level in B27-09 kept almost constant around 15 – 16.5m and did not show any increase (because of a trouble, the monitoring could not be conducted after 26 July). While in borehole B27-10, the groundwater level varied between 20.0m and 25.5m which is lower than the slip surface. In borehole B27-09, it becomes impossible to conduct the inclinometer monitoring from the depth of 19.2m. Within five days of 16 August, the accumulated rainfall in this area exceeded 600 mm. As a result, rapid increasing was observed in the surface ground extensometer No.4 and No.5 and ground extensometer in B27-12, and block 28-01 became active again.

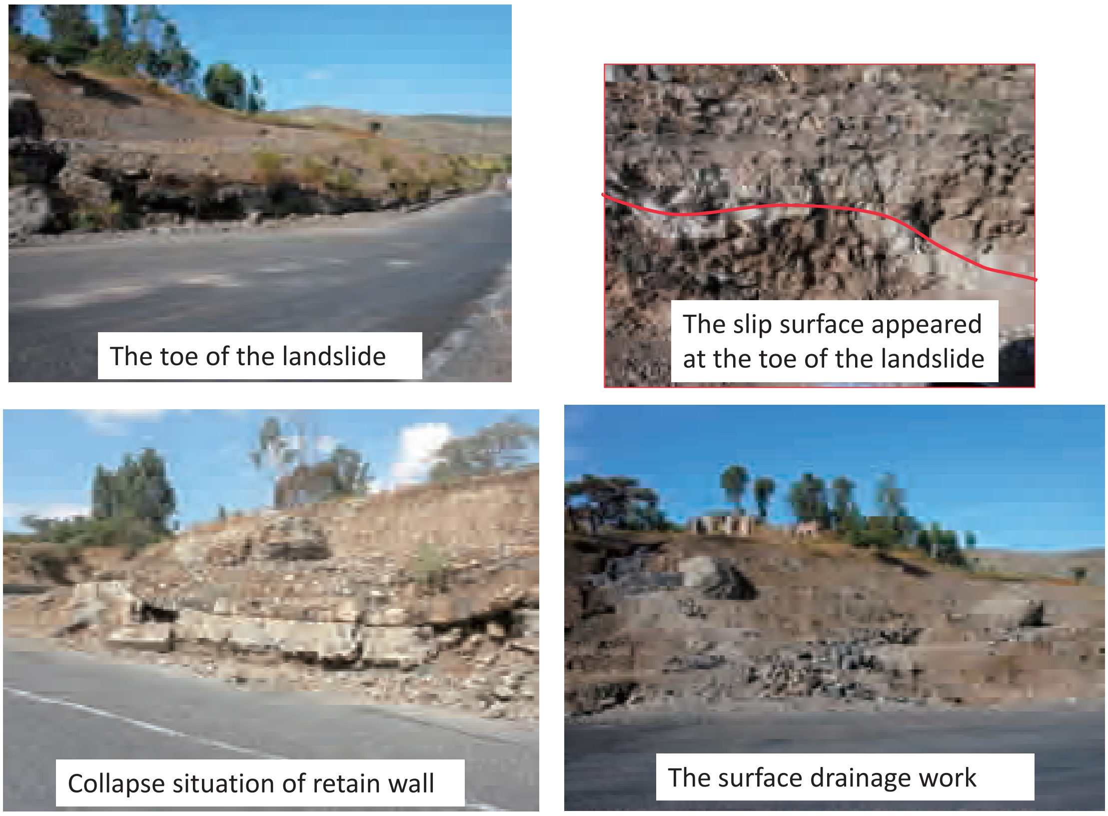


Photo 4.4.33 Landslide situation in L/S27 area

Table 4.4.8 summarizes the investigation and monitoring data for the L/S27 area. The detailed conditions of the monitoring by the equipment are described in the previous chapter 4.4.3.

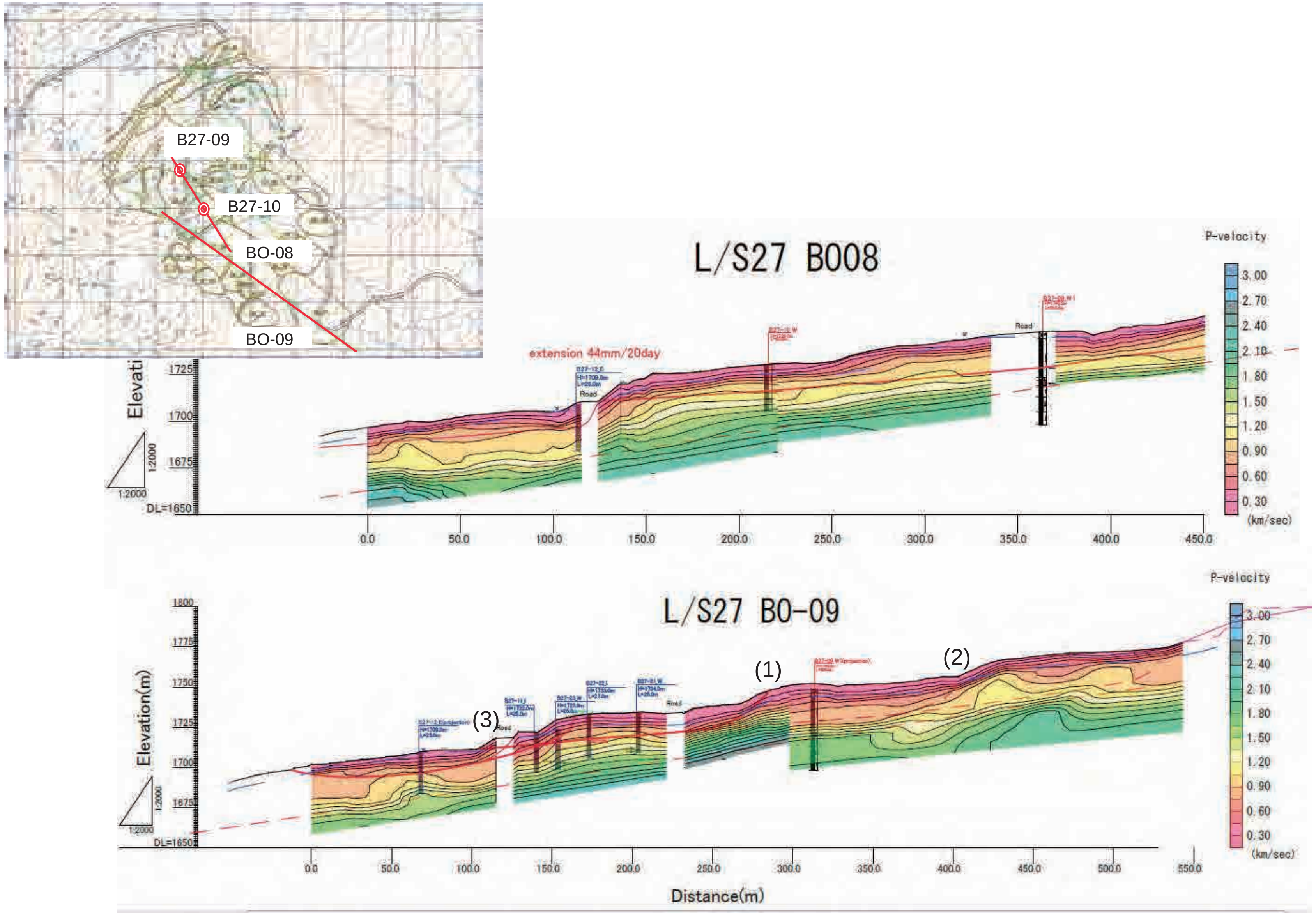


Figure 4.4.28 Landslide cross section of L/S27

Table 4.4.8 Investigation and observation data of L/S28-01 landslide block in L/S27

Clarity of crack	Drilling survey		Extensometer		
	Borehole number	Depth of slip surface	Equipment number	Installation day	Variation
28-00:clarity crack of scarp zone and side wall zone, end zone slip surface 27-05:clarity crack of scarp zone	B27-09	Under investigation.	EX-4	2 Jul.	15th.Jun.2011 : 61.8mm (compression 0.9mm)
	B27-10	Under investigation.			
	B27-11	8.9m:stratum boundary (silt rock and shale)			8th Oct.2011:99.1mm
	B27-12	13.4m:stratum boundary (silt rock and shale)			
	B27-21	12.4m:stratum boundary (silt rock and shale)	EX-5	2 Jul.	15th.Jun.2011.: 201.2mm tension
	B27-22	15.4m:stratum boundary (silt rock and shale)			7th Oct.2011:415.2mm
	B27-23	11.0m:stratum boundary (silt rock and shale)			

Borehole extensometer			Borehole inclinometer			Water level meter		
Equipment number	Installation day	Variation	Equipment number	Installation day	Variation	Equipment number	Installation day	Variation
B27-12	28 Sep.	No variation	B27-11	8 Oct.	borehole bending at 8.0m	B27-21	24 Sep.	Steady water level -22 to -24m maximum water level -21.9m (9/29)
		10thSep.2011 :48.4mm tension	B27-22	28 Sep.	15.0m	B27-23	9 Sep.	Steady water level -20 to -21m Maximum water level -20.3m (11/8)
						B27-09	29 June 2011.	29th Jun.to 26 July.:-16.533 to -14.932m
						B27-10	15 June 2011.	15th Jun.to 8 Oct.:-25.000 to -20.579m

	Seismic exploration/Velocity classification	Electric sounding / Specific resistance classification
1) Upper slope:	First layer (colluvial deposit）:-1.2km/s Second layer (sandstone）:1.2-2.5km/s	
2) Middle slope:	First layer (colluvial deposit):-1.4km/s Second layer (sandstone) :1.4-4.0km/s	
3) Lower slope:	First layer (colluvial deposit):-1.0km/s Second layer (sandstone):1.0-3.0km/s	

b.5 L/S28 area

The L/S28 belongs to the Landslide area II. The landslide block in this area continues from the upper slope to the lower slope. The large cracks of the scarp zone extend over the L/S27 area and the L/S28 area at an altitude of 1,810m. The depression zone, which is just below the scarp zone, is a source of water supply.

While the colluvial deposit in the L/S27 area is composed of siltstone and shale, the one in the L/S28 area is different for each borehole. The colluvial deposit in B28-11 is composed of siltstone and shale, which in B28-21 is gravel of basalt and tuff, and that in B28-31 is limestone.

In the past, a large landslide occurred in the L/S27 and L/S28 areas. That the colluvial deposit of L/S27 is silt stone and shale shows the possibility of a deep landslide exists. Because the colluvial deposit of B28-21, B28-31 and B28-32 are different from each other, geological differences between B28-31 and B28-32 may exist, and the landslide blocks in them may differ. Another borehole survey and continued investigation is required for confirmation.

Blocks 28-03 and 27-02 exist under the landslide which length is 400m from middle to upper part of the slope. Block 27-02, which has a scarp located at altitude of 1,715m, damages the road in the end zone.

Spring water is observed at three points in the rainy season of 2010: the depression zone (altitude 1,790m), the slope toe under the road (altitude 1,755m), and the end zone (altitude 1,725m). There are ponds in the slope toe on the valley side of the road and in the end zone of the dry season. Ponds form in the depression zone, and rain infiltrates from the zone. Therefore, infiltration water becomes spring water and oozes. The spring water level analyzed by the landslide cross section in Figure 4.4.29. The ground water level in B28-21 is different from the altitude of the spring water at the site. Therefore, the observed water level is not adopted in the stability analysis. Monitoring for the water level during the next rainy season is needed.

In consideration of above mentioned results of the seismic exploration, the investigation and the monitoring, slip surfaces were discussed. The thick red line in Figure 4.4.29 denotes the possibility of the slip surface. Slip surface (1), which was identified by drilling survey, is a landslide form the upper slope to the end of the field; slip surface (2), which is needed to be identified on additional surveys, is a large landslide deeper than (1); and slip surface (3) is a landslide on the lower slope.

Along the measure line BO-13, borehole investigation was conducted at B28-13 and BO-10 after July 2011 in this landslide. Both boreholes are located at the toe of the lower block of the landslide. In Borehole B28-13, an inclinometer was installed for monitoring, while, B28-23 was used to monitor the groundwater level. As with the monitoring results in B28-23, the water level increased by 4m from 6 July to 13 July, and increased by 6m from 20 July to 22 July. Two times water level increasing were recognized. The measurement of inclinometer became impossible when the depth reached 9.6m. The monitoring results of surface extensometer No.6 show that a gradual displacement was generated from February. The displacement is not caused by rainfall, but results from slope creeping. From July, the displacement at No.6 extensometer ceased.

Photo 4.4.34 Landslide situation in L/S28 area

Table 4.4.9 summarizes the investigation and monitoring data for the L/S28 area. The detailed conditions of the monitoring by the equipment are described in the previous chapter 4.4.3.

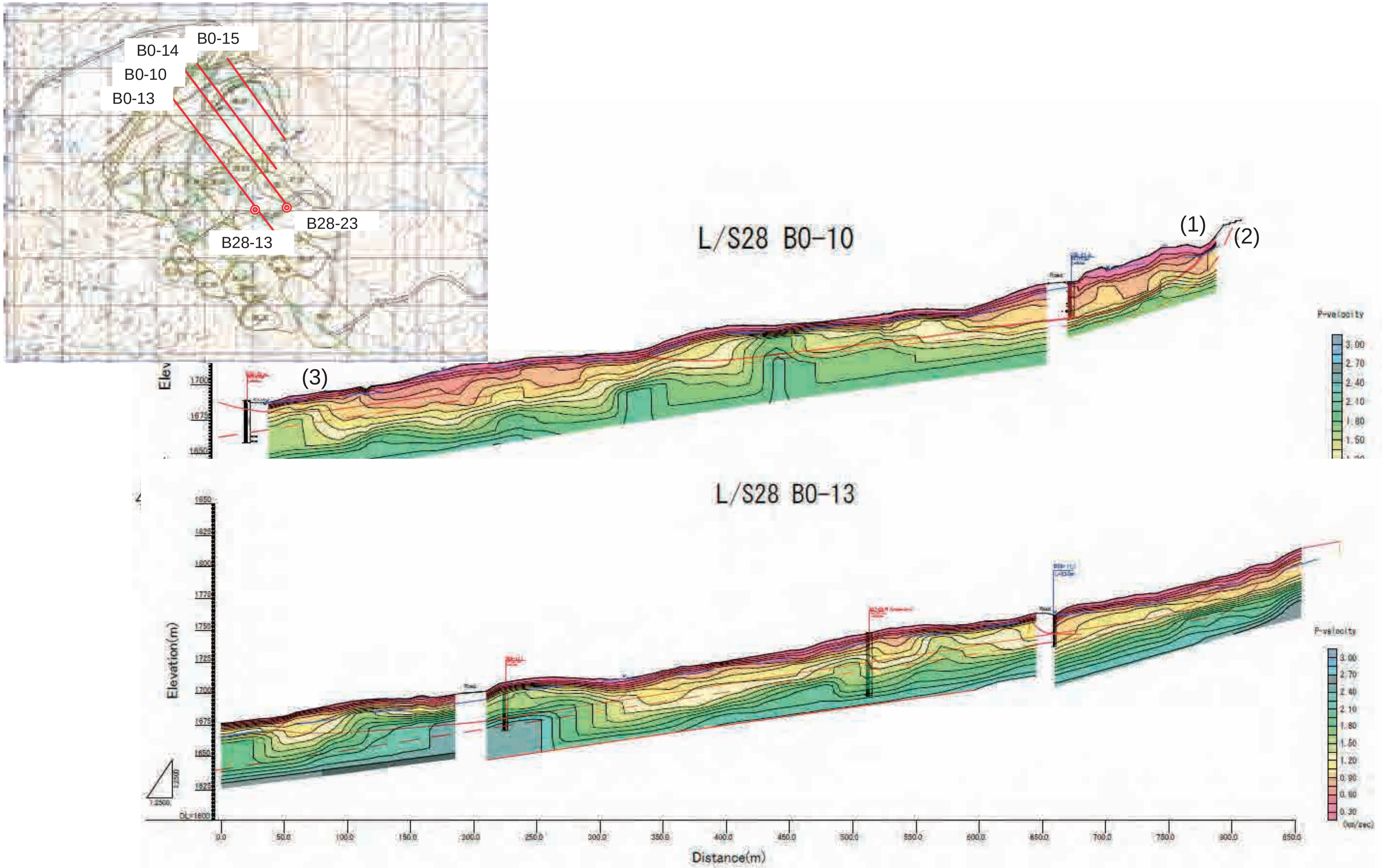


Figure 4.4.29 Landslide cross section of the L/S28 (1)

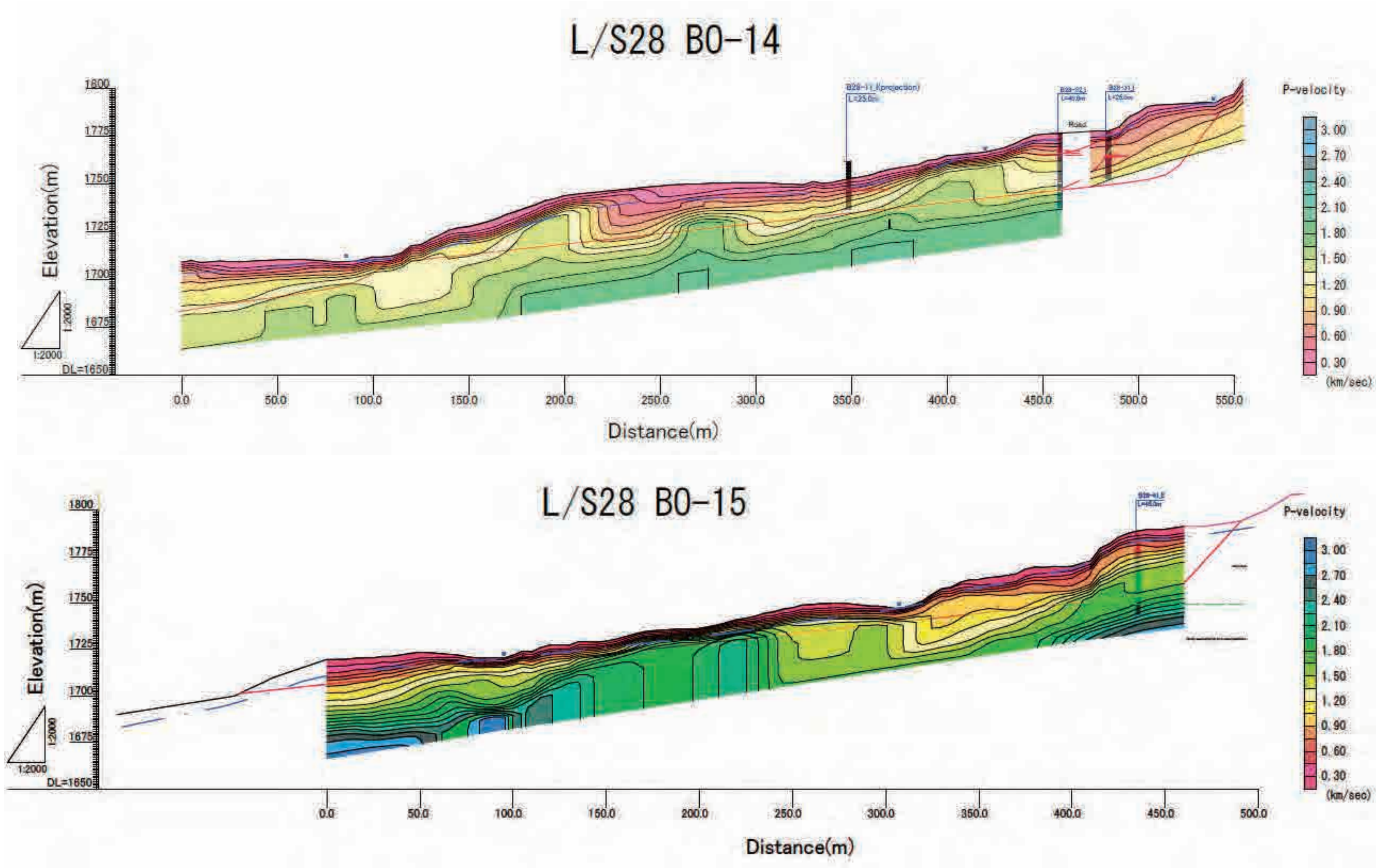


Figure 4.4.30 Landslide cross section of the L/S28 (2)

Table 4.4.9 Investigation and observation data of L/S28-05 landslide block in L/S28

Clarity of crack	Drilling survey		Extensometer		
	Borehole number	Depth of slip surface	Equipment number	Installation day	variation
28-05:clarity crack of scarp zone and side wall zone, existence of sink zone , spring water and pond in end zone	B28-11	13.95m:stratum boundary (silt and shale)	EX-6	2 Jul.	15th. Jun.2011.: 312.1mm extension(compression0.1mm)
	B28-13	Under investigation.			
	B28-21	17.0m:stratum boundary (limestone contained basalt gravel)			3th Oct.2011:284.4mmextension
	B28-23	Under investigation.			
	B28-31	14.0m:stratum boundary (basalt gravel and tuff), slip surface			
	B28-32	1.8m:stratum boundary (limestone)			

Borehole extensometer			Borehole inclinometer			Water level meter		
Equipment number	Installation day	Variation	Equipment number	Installation day	Variation	Equipment number	Installation day	Variation
B28-41	4 Sep.	0.1mm	B28-11	22 Sep.	10/8 immeasurable at 14.7m	B28-21	9 Sep.	Steady water level -20.0m Maximum water level -20.0m, Tiny variation (?)
			B28-31	9 Sep.	13.0m	B28-23	15 Jun.2011	15 Jun.to 8 Oct:-14.701 to -30.000m
			B28-32	8 Oct.	24.5m			
			B28-13		immeasurable at 9.6m			

Seismic exploration / Velocity classification	Electric sounding / Specific resistance classification
First layer (colluvial deposit):-0.8km/s Second layer (shale, basalt, limestone):0.8-1.4km/s	1) Upper slope: First layer (colluvial deposit):30-70Ωm Second layer (limestone):15-30Ωm 2) Middle slope: First layer (colluvial deposit):10-30Ωm Second layer (limestone):20-30Ωm 3) Lower slope: First layer (colluvial deposit):15-30Ωm Second layer (limestone):30-40Ωm

c. Summary of hydro-geological structure and landslide movement

The hydro-geological structure and landslide movement in Abay Gorge is summarized in Table 4.4.10.

Table 4.4.10 Summary of the hydro-geological structure and landslide movement in Abay Gorge

No.	Area	Hydro-geological structure and landslide mechanisms	Evidence behind the judgment		Note
1	L/S00	Surface anomalies of the landslide are a sliding of the rotation type inner colluvial deposit and the scarp zone is the buttress fill part of the road. It is judged that block 00-08 shows the movement that related to block 00-07 located in the lower side of block 00-08. Precipitation passes the water channel in the basalt layer where a lot of cracks exist. Groundwater gushes out as spring water along the limitation floor in the tuff layer etc. Though the landslide has been generated into the colluvial deposit, it is thought that the deep landslide along the tuff layer exists.	・The inclinometer monitoring result indicates that the accumulated displacement increases inner colluvial deposit.	◎	During the rainy season, the groundwater level in the borehole stayed nearly constant and there is no evidence showing groundwater level increasing. Besides, it is thought that there are smallest landslides along the embankment and potentially large landslides.
			・Series of consecutive cracks and slipping trace observed in the sidewall of block 00-07 in the field investigation.	◎	
			・Spring lines area found at during the field reconnaissance.	○	
			・The slickensides are recognized in the weathering weak tuffaceous mud and medium tuff layer of the lower layer in the drilling survey.	○	
2	L/S05	This area is divided into the upper slope block 05-01and the lower slope block 05-02. Both these blocks are the major landslide block that directly damaged the road. From the observation of the spring water situation, it is estimated that the groundwater from an upper terrace at outside of the landslide block is supplied from the right side of the upper block, and water level is high in the terrace of the upper block. Precipitation passes the water channel in the limestone layer where cracks exist in the lower block. The groundwater is flown out as spring water along the bottom of the colluvial deposit or the limited surface in the limestone.	・The inclinometer monitoring result indicates that the accumulated displacement at the bottom of colluvial deposit in the upper block and at the bottom of colluvial deposit or inner limestone in the lower block.	◎	During the rainy season, the groundwater level in the borehole stayed nearly constant and there is no evidence showing groundwater level increasing. Now the possibility of the deep sliding is low. But a slickenside is found at deeper formation within the lower block.
			・The cracks on the ground surface and retaining walls of the road due to the landslide exist.	◎	
			・Spring water site in the right side of the upper block suggests the existence of the training source of the underground water.	○	
3	L/S22	The landslide is adjacent to the road, and its displacement is large. The landslide consists of colluvial deposit and the bedrock is sandstone. Cracks have developed at the surface and extend close to the road shoulder. As the weathering of the sandstone in this area progresses, the soil mass collapses at the toe. It is thought that the landslide is generated by rising of the water level of the shallow groundwater due to direct infiltration of rainfall to the groundwater.	・The range and the movement of the landslide block are confirmed by the field investigation.	○	As the landslide is active, the movement has observed.
4	L/S27	The toe zone of block 28-01 is located in the scrap zone of block 27-04, and the two blocks are closely related. The slip surface of the landslide is the thin tuff layer located in the bottom of the colluvial deposit containing mainly basalt, and the bedrock is siltstone and shale alternation. It is thought that the ground water in this area is abundant and the ground water level of ground water is high by antecedent rainfall. It is thought that water level rises rapidly to the vicinity of the ground level by heavy rainfall in the rainy season and the landslide is generated by rapid increases of pore water.	・The inclinometer monitoring result indicates that the accumulated displacement increases in the bottom of the colluvial deposit.	◎	It is necessary to survey the depth of the slip surface at some distance from the road, and to investigate the groundwater level and the movement of the landslide.
			・The displacement of ground surface extension meter and borehole extension meter increase rapidly by rainfall 100mm at one time and continuous rainfall of 600mm or more.	◎	
			・The rise of the groundwater level by the rainfall was observed at a position nearby the toe of the landslide.	△	
5	L/S28	In this area, the landslide block continues from the upper slope to the lower slope. The fragments of colluvial deposit in this area is different for each borehole such as siltstone-shale, gravel of basalt-tuff, limestone and others. It is assumed that a large-scale landslide was generated in the past, and there are shallow and deep slip surfaces. It is thought that the groundwater channel that has pressure exists in the deep sliding for hydro-geological structure.	・The inclinometer monitoring result indicates shallow sliding.	◎	The stratum structure is roughly understood by the geological survey. Information of deep slip surface is not observed.
			・The sinking zone is formed in the scarp zone of block 28-05 and also several ponds are seen in the toe zone of block 28-05.	○	
			・The displacement in the scarp zone of the landslide indicates creeping movement.	△	
			・The rise of the groundwater level by the rainfall was observed at a position nearby the toe of the landslide.	○	

Annotation: ◎: The certainty is very high, ○: The certainty is high, △: Further verification is necessary though the possibility is high.

4.5 Stability Analysis of landslides

4.5.1 General

The objectives of stability analysis are as follows;

- To calculate a safety factor and restraint stress to be needed for design of countermeasure
- To get soil parameters (c, ϕ) with back calculation

Generally, stability analysis for landslide is preceded as following procedure.

1) Geological reconnaissance at site
2) Setting up traverse line for the analysis
3) Designing drilling survey, monitoring and geophysical exploration
4) Estimation of slip surface by the survey result
5) Monitoring of the ground water level and movement of landslide
6) Setting up landslide model
7) **Stability analysis**

Laboratory test for the rock/soil samples may is done for stability analysis. However, it is difficult to adjust the result values of laboratory test into stability analysis, because the value does not represent the real situation around the slip surface in the ground. Therefore, “a reverse operation” is usually utilized on stability analysis for landslide.

The status of stability analysis method is mainly classified as follows.

a. Two-dimensional analysis (normal operation)
This is analysis method for design work. All frictional resistance except at the bottom of the slide mass is ignored in the method. It is not suitable for real situation in the ground.

b. Two-dimensional analysis (reverse operation)

c. Three-dimensional analysis (single strength, reverse operation)
Average strength on single slip surface is used for these stability analysis methods. It is impossible to use laboratory test value for these methods. Therefore, safety factor for analysis is set in consideration of the real situation in the ground.

d. Three-dimensional analysis (multiple strengths, normal operation)
This stability analysis method is acceptable multiple strength. Therefore, it is possible to use laboratory test result.

In case the safety factor is calculated with laboratory test results, three-dimensional analysis (multiple strengths) is only acceptable in stability analysis based on limit equilibrium method. This method requires exact physical values for slip surface and other destructive surface, and the values are useful for actual stability factor in the ground.

The reverse operation is available way for the stability analysis, in case that neither landform nor groundwater changes in a large scale. However, it is preferable to use the normal operation analysis by the laboratory tests result.

- In case of artificial alteration on landform
- In case of drastic change of shear strength by artificial water filling
- In case of significant low strength part in slip surface

In the Project, the main purpose is comprehension of the basic methodology of landslide survey and analysis. Therefore, two-dimensional stability analysis method with reverse operation shall be adopted.

4.5.2 Safety factor in landslide analysis

Safety factor F_s is defined as the ratio of resistance force against landslide soil mass to force when landslide soil mass starts sliding along the slip surface. F_s =1 means when resistance force and sliding force are balanced. F_s >1 means the landslide is stable whilst F_s<1 is unstable or sliding.

$$F_s = \frac{\text{Resistance force against landslide soil mass}}{\text{Force when landslide soil mass starts sliding along the slip surface}}$$

If the slip surface and pore water pressure plane are decided, F_s is obtained from cohesion c' and shear resistance angle φ', which are constants for soil strength of slip surface, using the stability analysis formula.

Since F_s =1 when the land mass starts sliding, F_s is decided by considering the active state of the landslide for $0.95 < F_s < 1$ if a landslide occurs.

Safety factor is defined for each landslide condition in Table 4.5.1 from Disaster Notebook edited in Japan Construction Engineer's Association (2010). The Study Team uses the safety factor in the Project.

Table 4.5.1 Definition of safety factor for landslide

Safety factor	Landslide condition
F_s =0.95	Case in moving continuously anytime
F_s =0.98	Case in moving continuously for corresponding to rainfall etc.
F_s =1.00	Case in settling down of the landslide

Japan Construction Engineer's Association (2010)

4.5.3 Selecting parameters

The parameters for landslide stability analysis are as follows;

- γ_t : wet unit weight (wet density)
- u : pore water pressure
- c': cohesion (as a soil strength constant)
- φ': shear resistance angle (as a soil strength constant)

The volume and configuration of the landslide mass is determined by investigating and monitoring the landslide. Pore water pressure is derived from the critical pore water pressure when the land starts sliding with water level monitoring. cohesion and shear resistance angle (particularly shear resistance angle) are obtained from the shear test of the slip surface soil.

In the current investigation in Abay Gorge, the volume and configuration of the landslide and the wet unit weight γ_t are identified. The unidentified parameters are the pore water pressure *u* (particularly the critical pore water pressure), cohesion *c*' and shear resistance angle *φ'*. Because landslides frequently occur in the rainy season in the Abay area, cohesion *c*' is considered to be relatively small. Samples as soil mass of slip surface are obtained when drainage well is dug or when the slip surface is exposed to the ground surface.

Critical pore water pressure when the land mass starts sliding in the rainy season is necessary parameter because it is indispensable for ensuring stability analysis accuracy and determining landslide countermeasures.

4.5.4 Stability analysis method

There are multiple landslide blocks in the four investigated areas (except L/S22). Previous investigations have suggested that there are shallow landslides appearing as ground surface phenomena and deep potential landslides. The possibility of a deep potential landslide will be discussed after the next investigation. In this report, the stability of shallow landslides occurring in the ground surface phenomena is analyzed.

The landslide stability is analyzed using “Fellenius method”, “Bishop method”, “Spencer method”, “Janbu method”, “Morgenstern & Price method” and all that. Selected factors and the feature of each method are shown in Table 4.5.2.

Table 4.5.2 Landslide slope stability methods and selected factors

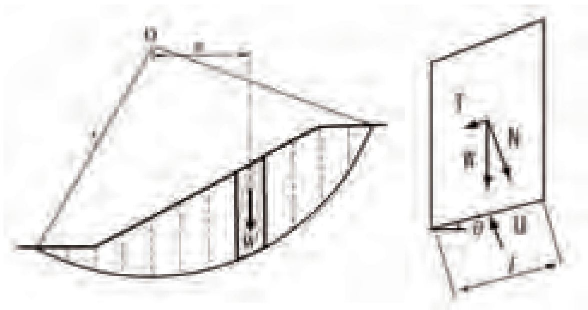
name of method	selecting factor of stability analysis method						feature
	grand water condition		acceptable slip bsurface figure		type of landslide		
	confind	free	rotational	other	rock slide	other	
Fellenius method	○		○			○	this formula basically give small exact solution of stability factor. (sometime large)
Modified Fellenius method		○	○			○	using free grondwater, but not accept a seepage flow
Bishop method	○		○			○	this formula give almost exact solution of stability factor.
simple Bishop method	○	△	○				
Jambu method	○	△	△	○		○	this formula give almost exact solution of stability factor. On the other hands, this method propose other fomula for submerged slope, and for rotaitional slide.
SHIN-Jambu metod	○			○	○		Based on Janbu method, modified for rock slide phenomenon analysis.
Spencer method	○		(1)	(2)	△	○	this formula is good for exact solution of stability factor analysis, but sometime this formula has multiple solution depend on way of putting parameter.
Morgenstern & Price method	○			○		○	

○: well accept △,(1),(2): has other fomula ″ ″: not so good result

Fellenius method is most popular way of stability analysis in Japan because 1) the calculation is very simple, 2) the calculated value could be safer side for countermeasure. However, Kinoshita and Enokida (2000) argued that the possibility which the calculation result differs from precise solution more than 1%, up to 27%. Therefore, it is preferable to confirm the result by re-calculating with several methods.

The slip surfaces of four landslide areas are non-circular (complex) slide. The stability analysis is implemented by using "modified Fellenius method" and "simple Janbu method" generally employed in Japan. Two typical stability analysis methods are explained below.

a. Modified Fellenius method

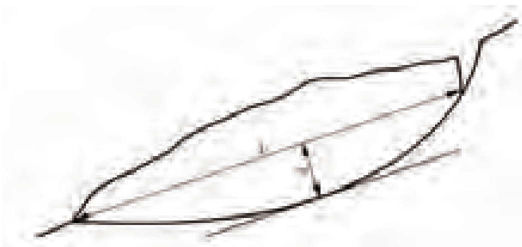


The Fellenius method is also called a Sweden method or a simple method, and is based on the balance of the moment between soil weight and the shear resistance acting on the slip surface. In case of a large inclination angle at slice of slip surface, Wcosα-ul may become minus in this method. Therefore, Wcosα-ul is generally treated as 0. Actually shear stress occurs in the slip surface, so that safety factor is smaller than true value. This is corrected by the modified Fellenius method that employs the effective soil weight W'=W-ub instead of the soil weight W.

$$F_s = \frac{\sum\{c'l + (W - ub)\cos\alpha \cdot \tan\phi'\}}{\sum W \sin\alpha}$$

Here, F_s : safety factor, c' : cohesion, φ': shear resistance angle,
W: soil weight, u: pore water pressure, b: slice width,
$W=\gamma_t hb$, γ_t : soil unit weight, h : soil height,
l: slice length of slip surface, α: inclination angle of slip surface.

b. Simple Janbu method



The Janbu method is, from the point of view of the balance of the horizontal stress and vertical stress in each slice, based on that the total stress in the entire soil mass is balanced as zero. It is applied to tabular-shape slides controlled by the soil weight and the shear resistance on the bedrock, and to complex slides in which are mixed circular slides on the scarp zone and the end zone and tabular-shape slides on the middle zone in the slip surface.

$$F_s = f_0 \frac{1}{\sum W \tan\alpha + Q} \sum \frac{c'b + (W - ub)\tan\phi'}{n_\alpha}$$

Here, F_s : safety factor, c': cohesion, φ': shear resistance angle,
W: soil weight, u: pore water pressure, b: slice width,
α: inclination angle of slip surface,

Q: effective stress in tension crack of scarp zone,
n_α is defined as

$$n_\alpha = \cos^2\alpha(1+\tan\alpha\cdot\tan\phi'/F_s)$$

f_0 : correction coefficient,

$$f_0 \cong \left(50\frac{d}{L}\right)^{1/33.6}$$

L : distance between the toe and crack at the scarp
d: distance between L and a line of parallel to L tangential line on the slip surface.

Figure 4.5.1 shows analysis procedure of modified Fellenius method and simple Janbu method.

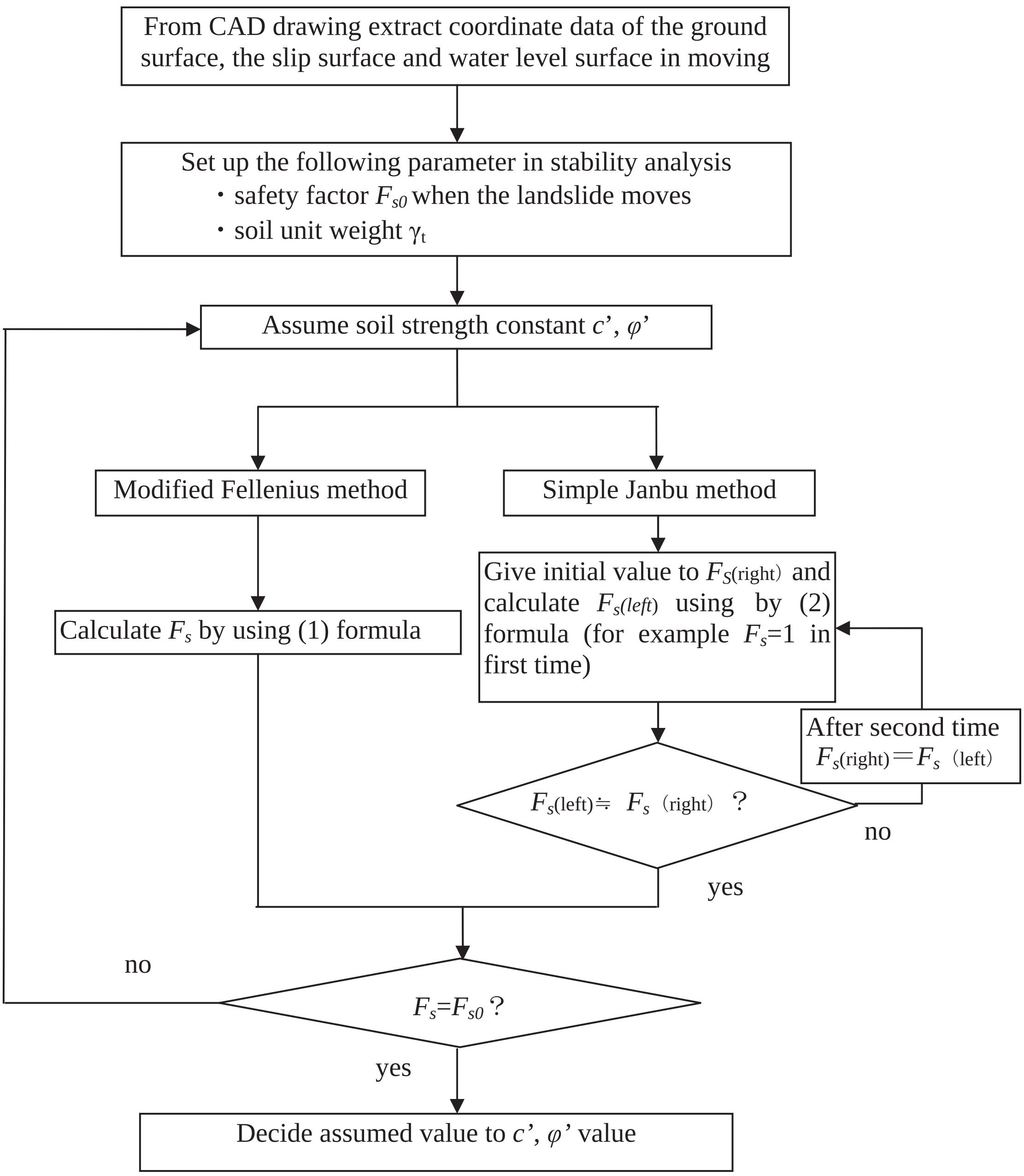


Figure 4.5.1 Analysis procedure in stability analysis

4.5.5 Result of stability analysis

The landslide stability analyzed using the modified Fellenius method and the simple Janbu method. Analysis cross section of each area is shown Figure 4.4.25 to Figure 4.4.29.

Wet unit weight of soil mass for landslide stability analysis is used generally as γt=18kN/m3 in Japan. Wet unit weight of Loamy layer from volcanic ash and clay layer are smaller and colluvial deposit contained hard lock and weathered rock are larger than γt=18kN/m3.

Wet unit weight of moving soil mass is shown Table 4.5.3.

Table 4.5.3 Design value of soil constant in Japan

Classification		Soil state		Wet unit weight $[kN/m^3]$
Embankment	Gravel and Sand with Gravel	Compacted		20
	Sand	Compacted	Wide grain size	20
			Sorted	19
	Sandy Soil	Compacted		19
	Cohesive Soil	Compacted		18
	Kanto Loam	Compacted		14
Natural Ground	Gravel	Dense or wide grain size		20
		Not dense or sorted		18
	Sand with Gravel	Dense		21
		Not dense		19
	Sand	Dense or wide grain size		20
		Not dense or sorted		18
	Sandy Soil	Dense		19
		Not dense		17
	Cohesive Soil	Hard (yield under strong pressure of a finger)		18
		A little soft (penetrate under pressure of a finger)		17
		Soft (penetrate under pressure of a finger easily)		16
	Clay and Silt	Hard (yield under strong pressure of a finger)		17
		A little soft (penetrate under pressure of a finger)		16
		Soft (penetrate under pressure of a finger easily)		14
	Kanto Loam			14

Japan Road Association (2010)

Soil in investigation area is silt with gravels, which is hard cohesive soil or undense gravel in Table 4.5.3. Therefore wet unit weight of a moving soil mass is determined as 18kN/m3 in the stability analysis in the Project. However it is desirable to measure the unit weight in the site as possible.

The landslide block in each area is moving, and the landslide activates when ground water rises in the rainy season. Therefore it assigned $c' \fallingdotseq 0$. Although there are damages on the road due to cracks and subsidence, the landslide is not moving so much. Therefore, the safety factor F_s should be less than 1.0, it is reasonable to adopt 0.98 for the area.

As an example of back calculation of the stability analysis, the procedure at L/S00 is shown in following Figure 4.5.2 and Figure 4.5.3.

The surface profile and estimated water level lines are plotted as indicated in the following figures. The estimated sliding surfaces are also inserted on the cross section.

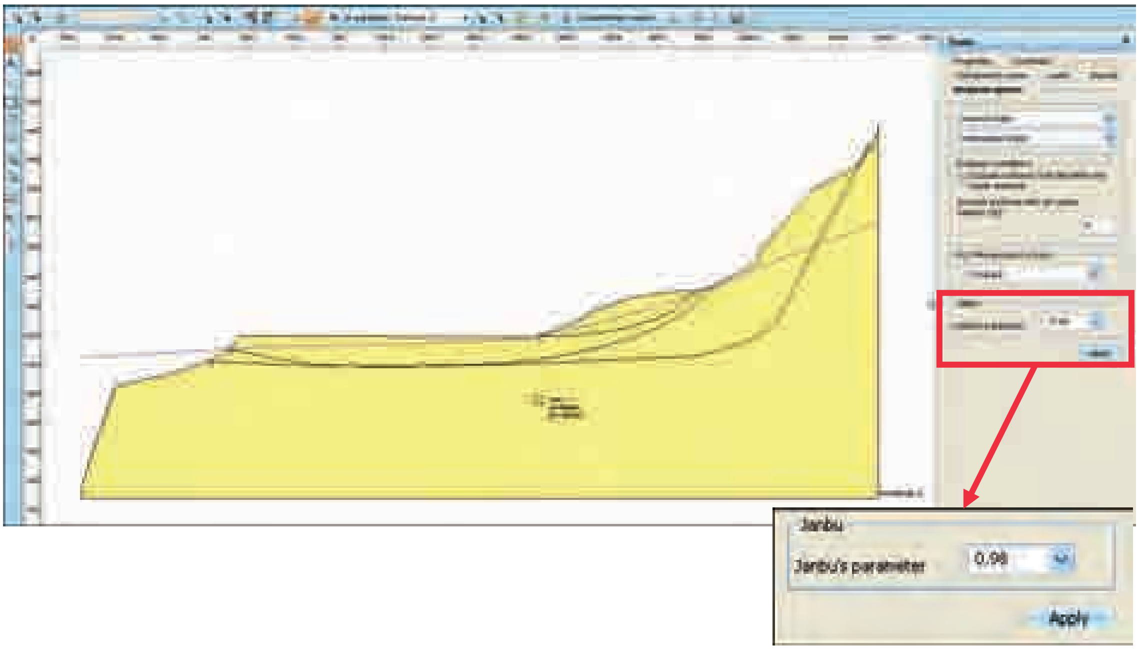


Figure 4.5.2 An example of back calculation of the stability analysis (1)

Here the safety factor is set as 0.98 in regard to the Table 4.5.1 knowing that the slip surface (2) in Figure 4.5.15 is considered as the state of less stable in regard to the balance of the rock mass verses internal friction angle and cohesion of the sliding plane. In this case, the Janbu method was applied to the back calculation to obtain the soil parameters.

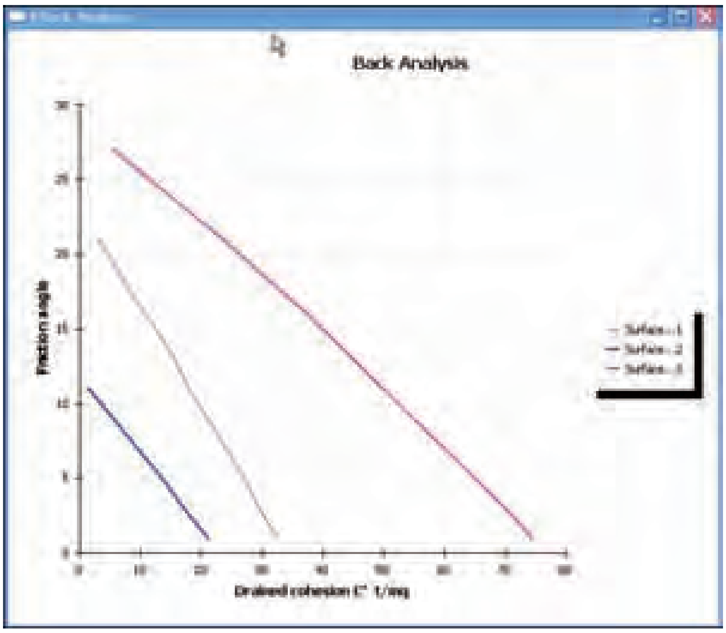


Figure 4.5.3 An example of back calculation of the stability analysis (2)

The result of the stability analysis for each investigated areas is shown in Table 4.5.4. Almost the same results for both the modified Fellenius method and the simple Janbu method are obtained.

The slip surface is a tuff layer in both L/S00 and L/S27, here φ'≒10° is obtained. The landslide in L/S05 and L/S28 is a colluvial deposit slide, and φ' is 26° (L/S00) and 16° (L/S27), exceeding φ' of the tuff layer.

Table 4.5.4 Stability analysis results (shear resistance angle φ')

Area	Modified Fellenius method	Simple Janbu method	Geological information of slip surface
L/S00	10.8	10.7	Slip layer: embankment and tuff layer in colluvial deposit, complex slide
L/S05	26.3	26.6	Colluvial deposit slide, Bedrock: limestone
L/S27	10.2	10.0	Colluvial deposit slide contained basalt Bedrock: siltstone and shale
L/S28	16.3	16.1	Colluvial deposit slide, Bed rock: limestone contained basalt

Figure 4.5.4 plots the shear resistance angle of the slip surface in each geology produced by Japan Landslide Society (2011). The shear resistance angle of Neogene tuff ranges from 3 to 17°, and 10° obtained here is the average value of Neogene tuff.

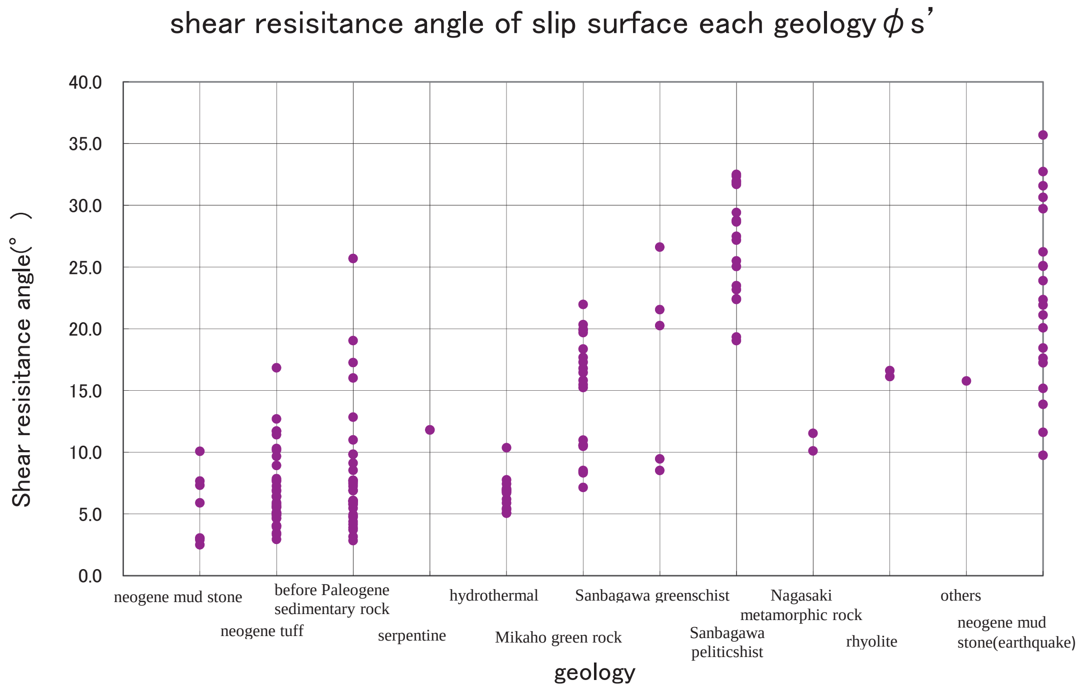


Figure 4.5.4 Shear resistance angle of the slip surface (Japan Landslide Society, 2011)

4.6 Utilization of slope stability analysis

4.6.1 Principle of using the result of stability analysis

The most important role of slope stability analysis in conducting landslide countermeasure works is to reasonably evaluate the appropriate type and amount of the landslide countermeasure works. For example, if groundwater drainage work is carried out, the factor of safety of the landslide will be certainly improved. However, if slope stability analysis is not conducted, it will be difficult to evaluate how much the factor of safety has been improved. In designing stage, it is necessary to conduct the slope stability analysis to determine the amount of groundwater which should be drained out. After the execution of a countermeasure, the slope stability analysis should also be conducted to evaluate its effectiveness. When a combination of countermeasure works such as groundwater drainage and counterweight fill work has been planned, their positions and configurations which would be most effective should be carefully chosen through the slope stability analysis.

In a landslide countermeasure project, combinations of different countermeasure methods should be tested before determining the grand design of the countermeasure plan. Generally, multiple combinations of countermeasure works should be examined according to their cost effectiveness and feasibility. Figure 4.6.1 shows the changes in factor of safety when multiple countermeasure works are applied. Assuming there are two possible combinations to achieve a planned factor of safety (Fp), i.e., a combination of A and B, and a combination of C and D, the necessary number of each countermeasure and the resulting increments of the factor of safety can be estimated through the stability analysis. Based on the stability analysis, an appropriate combination can be decided according to the cost effectiveness and feasibility.

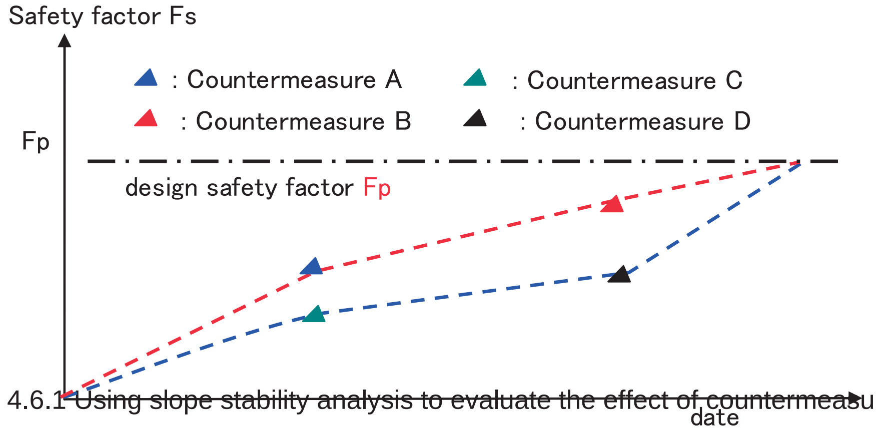


Figure 4.6.1 Using slope stability analysis to evaluate the effect of countermeasure works

Slope stability analysis should also be conducted after the countermeasure construction is completed. For example, after a groundwater drainage work, it is necessary to monitor the groundwater level to verify the effectiveness and to confirm whether the predicted improvement is achieved. If the improvement of the stability is smaller than what was predicted, additional countermeasure works should be considered.

Depending on the values of soil parameters adopted in the analysis, the effect of countermeasure works which will be calculated may vary. For example, when using a larger friction angle φ than the actual value, the effect of groundwater drainage works is usually overestimated. When the groundwater drainage work is used as a main control work, it is therefore necessary to choose a value of friction angle appropriate for the target sliding surface in order to properly evaluate its effectiveness. In contrast to this, cohesion (c) has obvious influence when calculating the effect of earth removal works. When a larger cohesion (c) than the actual value is used, the effect may usually be overestimated. Cohesion (c) value should be properly chosen in the evaluation of the earth removal work.

Occasionally, deformation can occur in a landslide, even after the planned factor of safety is achieved according to result of the slope stability analysis. In such cases, either cross-sectional geometry of the sliding surface, sliding direction, or soil parameters is probably wrong and thus needs to be re-examined.

4.6.2 Initial assessment of the effect of countermeasure works

The method of initial assessment is different for each type of countermeasure works. The following are explanations of each method.

a. Initial assessment of the effect of groundwater drainage work

It is necessary to predict how the groundwater level decreases when different types of drainage works with different configurations are implemented. In the initial assessment, the highest groundwater level recorded in a rainy season should be used as the initial condition. Then, the declined amount of groundwater level can be predicted through hydrological analysis and seepage flowing analysis. In this kind of analysis, Thiem's hydraulic equation is often employed to obtain the amount of inflow, and there is a finite difference method (FDM) software MOD-Flow for seepage flow analysis. The predicted groundwater level then can be used in the longitudinal section for stability analysis. The analysis verifies how much the factor of safety is improved. Generally, the prediction accuracy is relatively low. Hence, groundwater should be developed after groundwater drainage work is executed to further assess the effectiveness of the drainage works.

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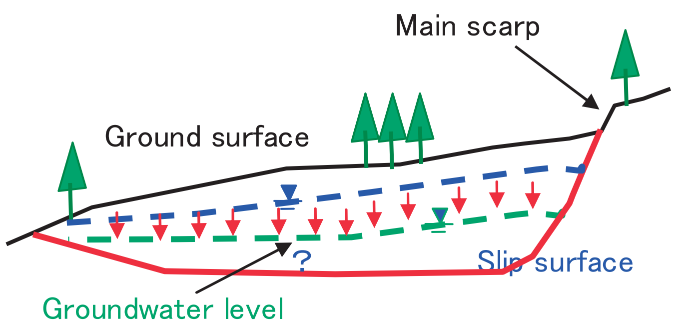


Figure 4.6.2 Groundwater level declining prediction after drainage work

b. Initial assessment on the effect of surface water drainage

It is difficult to predict the fluctuations of groundwater level when different types and configurations of surface water drainage work are implemented. Surface water drainage work is easy and relatively inexpensive to implement compared to other counter structures. As a result, the initial assessment is not conducted. Only verification of measure's effect is conducted after the countermeasure construction work is executed.

c. Initial assessment on the effect of earth removal work, counterweight fill work

As shown in Figure 4.6.3 and Figure 4.6.4, when topography is changed by implementing earth removal work and counterweight fill work, topographic geometry of the longitudinal cross-section should reflect the change so that the factor of safety after the implementation can be properly calculated.

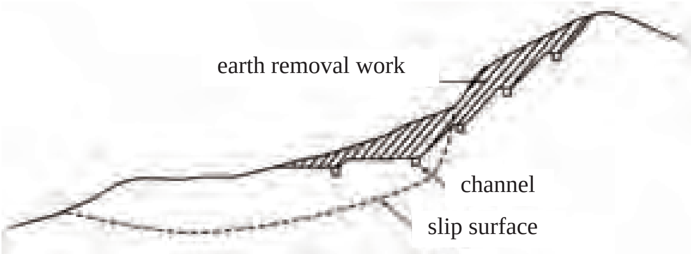


Figure 4.6.3 Earth removal work and cutting slope surface

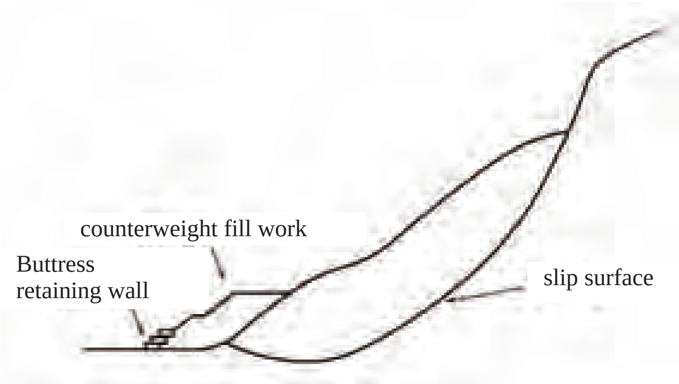


Figure 4.6.4 Buttress retaining wall and counterweight fill

d. Initial assessment of the effect of restraining works

The effect of restraining works can be evaluated with the following equation.

$$F = \frac{\sum S + P_s}{\sum T - P_m}$$

Here, Σ S, Σ T: The numerator and denominator of stability analysis equation; Ps: increment of shear strength resulted from the restraint work; and Pm: restraint force (in the opposite direction to the driving force).

In the formula, Ps is the increment of shear strength resulted from the restraint works, such as that can be obtained from anchor works. Pm is the restraining force, such as the detaining effect of the anchor works and the deterrent of the pile works and the shaft works.

4.6.3 Verification of the effect of the countermeasure works

After the execution of the countermeasure works, their effect can be verified by deformation monitoring on the landslide. For example, the countermeasure works can be verified as valid when the deformation becomes dormant during an intense rainfall, or no deformation is detected at the landslide. The following are the verification methods to check the improvement of the factor of safety for each countermeasure work.

a. Verification of the effect of surface water drainage and groundwater drainage

The effect of groundwater drainage is evaluated through the comparison of current groundwater level to the previous groundwater level before the drainage work is implemented. Generally, the highest groundwater levels before and after the execution of the drainage work are used in the comparison. However, the groundwater level changes frequently according to the amount of rainfall. Hence, groundwater response to precipitation pattern can be modeled using the monitoring data that was obtained before the execution of the drainage work. By using the model, groundwater level can be simulated in response to an intense rainfall after the drainage work, which then can be compared with the monitored groundwater level. Through applying this method for all of the groundwater monitoring points along the longitudinal section, and conducting the slope stability analysis, the effect of the drainage work can be verified.

b. Verification of the effect of earth removal work and buttress counterweight fill work

If an earth removal work and buttress counterweight fill work is conducted exactly as they were planned, the same effect should be achieved as expected. If the earth removal work and buttress counterweight work are not implemented as planned, another slope stability analysis should be conducted using the actual longitudinal topographic section after the execution of the countermeasure works.

c. Verification of the effect of restraint works

For the restraint works, if they are executed exactly according to the plan, the effect should be the same as expected.

4.6.4 Modification of the shear strength parameter of the soil

For a landslide during monitoring period, the factor of safety becomes exactly 1.0 (F=1.0) when the deformation starts to occur. If the groundwater is monitored in this period, the groundwater level at that deformation starting point is called the critical groundwater level (F=1.0). Using the critical groundwater level, the shear strength parameter of the soil in sliding surface can be obtained through back-analysis in the slope stability analysis. Using this approach, the calculated shear strength parameters can become closer to the true values. Using this modified shear strength parameter, relatively accurate estimation on the effect of countermeasure work can be obtained.

4.6.5 Trial calculation concerning the assessment on the effect of the countermeasure

A trial calculation was conducted to evaluate the effect of the countermeasure works along the L/S-00. Figure 4.6.5 shows the longitudinal section prepared for the stability analysis. The factor of safety was set as 0.98, and the shear strength parameters of soil were obtained through back-analysis. However, in this site, because normal groundwater level was not monitored, the groundwater level was set according to that observed during slope excavation.

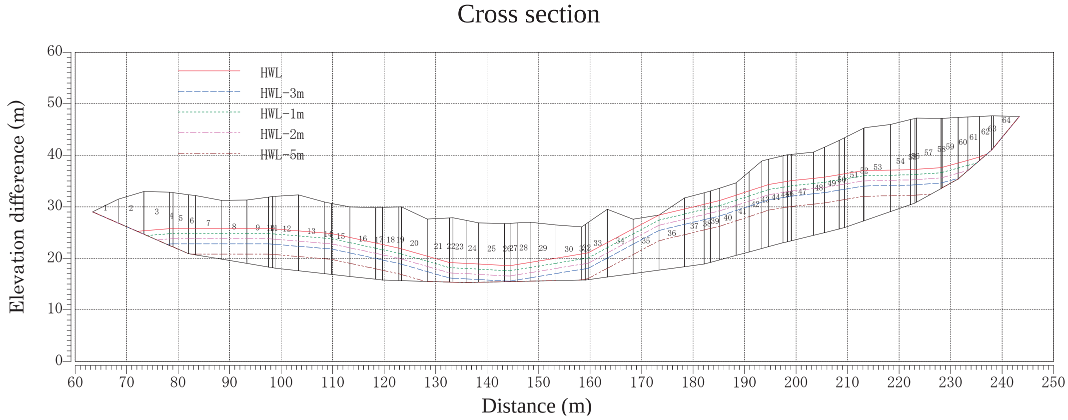


Figure 4.6.5 Longitudinal section used in the trial calculation of stability analysis

Figure 4.6.6 shows the trial calculation result representing the effect of the groundwater drainage works. It indicates increase in the factor of safety in response to the decline of groundwater level. Two cases are plotted in the figure. Using two sets of specified shear strength parameter ϕ, where one is $\phi = 6°$ and the other is $\phi = 4°$, cohesion (c) was calculated through back-analysis. The results were plotted as blue and pink lines. According to the result indicated in blue when $\phi = 6°$, by lowering the groundwater level (highest groundwater level) by 6 m, the planned factor of safety (Fp = 1.2) can be achieved. However, in the case when $\phi = 4°$, the planned factor of safety cannot be achieved even by decreasing the groundwater level for 10 m. It is therefore clear that the effect of groundwater drainage may be overestimated when using a larger friction angle.

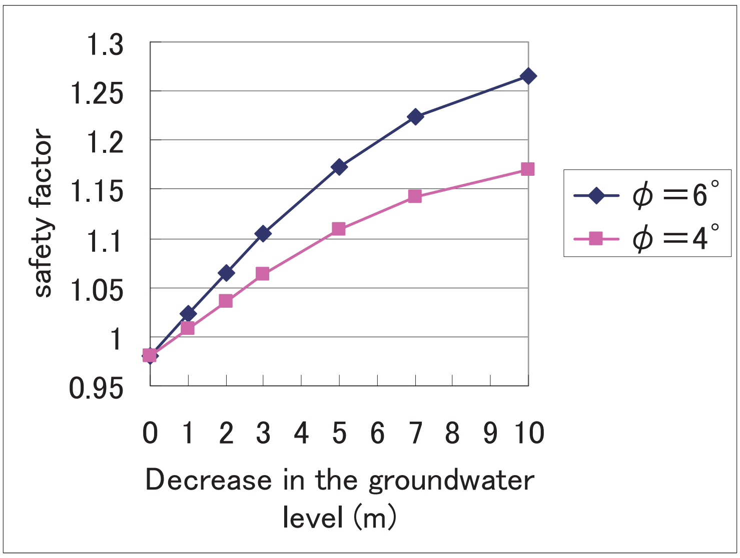


Figure 4.6.6 Changes in the factor of safety in response to decrease in groundwater level

Next is an example to show the trial calculation for a landslide with fill work in the middle of the slope. Figure 4.6.7 shows the longitudinal section used in the stability analysis. In the middle of the slope, when fill work with a depth of 1 to 3m was executed, the factor of safety increased from 0.98 to 1.02.

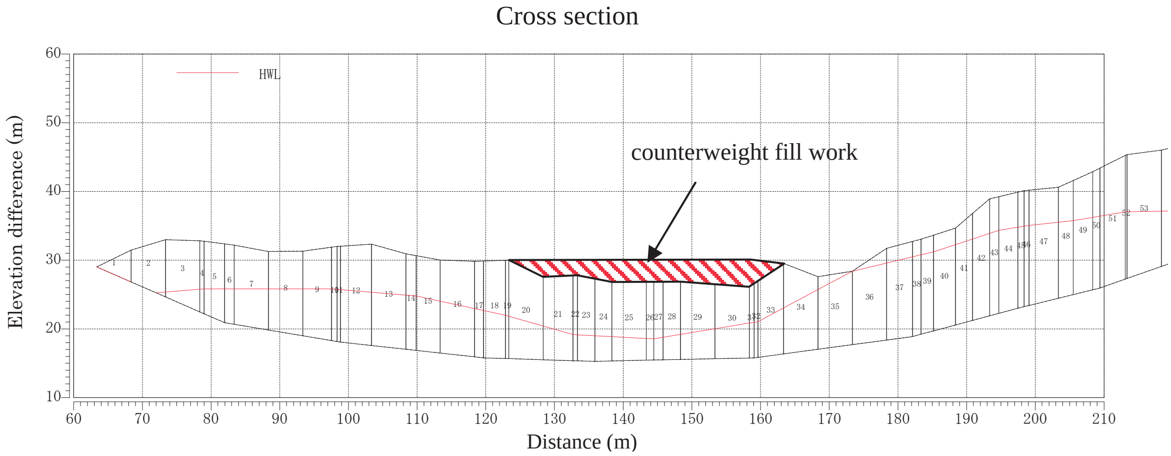


Figure 4.6.7 Longitudinal section for trial calculation of effect evaluation with fill work mid-slope

Figure 4.6.8 shows a longitudinal section of a landslide for trial calculation of stability analysis in which fill work is implemented on a road at the head. When fill work about 1 m thick was conducted at the landslide head, the factor of safety changed from 0.98 to 0.92.

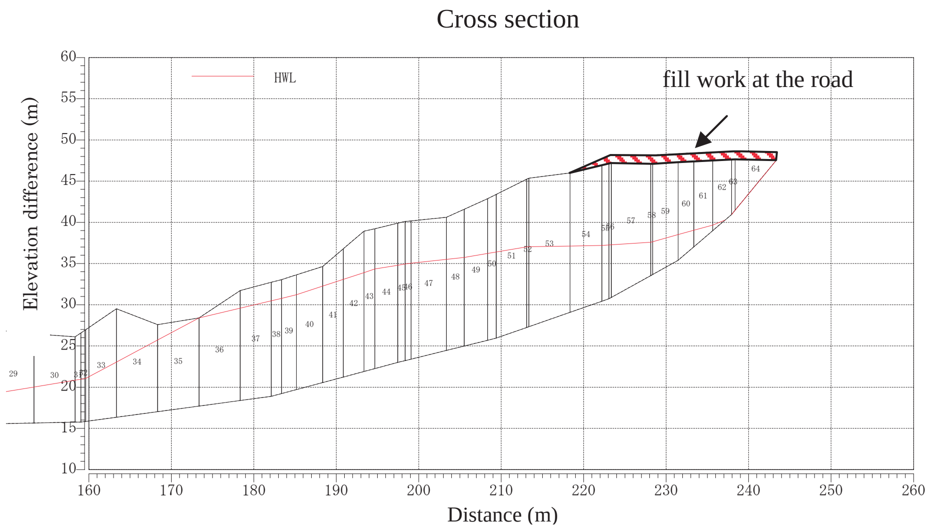


Figure 4.6.8 Longitudinal section for trial calculation of effect evaluation with fill work at the landslide head

When pile works (steel pipe piles) are implemented as restraining work, a trial calculation helps to decide how many steel pipe piles should be used. The result shows that to improve the current factor of safety of 0.98 to 1.2, steel pipe piles of φ500mm×t40mm should be arranged at an interval of 1.9m. Another calculation also shows that, if a groundwater drainage work is executed at first to lower the average groundwater level by 3m, which means the factor of safety can be improved to F≒1.1, and then to improve the factor of safety from 1.1 to 1.2, it is necessary to arrange φ350mm×t25mm steel pipe piles at an interval of 1.9m.

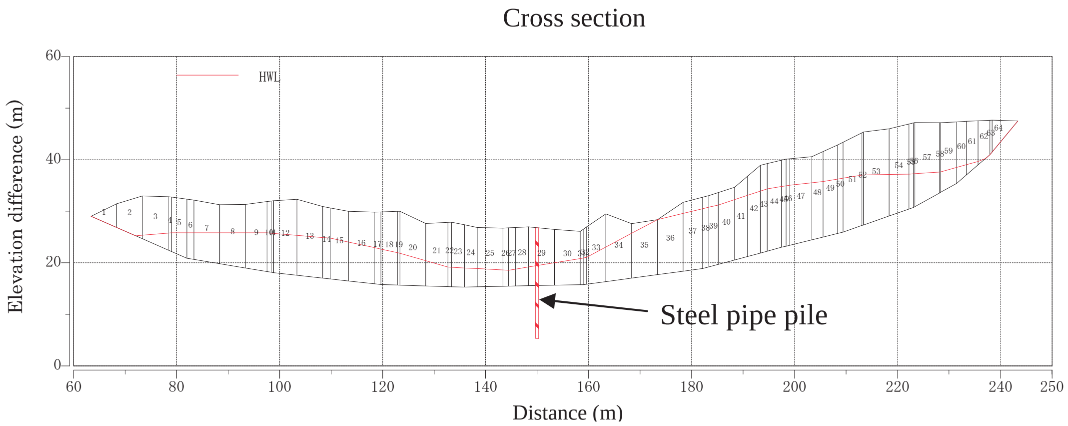


Figure 4.6.9 Longitudinal section for trial calculation of effect evaluation with steel pipe piles

4.7 Rockfall Analysis

It is important to predict the motion mechanism of rockfall accurately and to take countermeasures against it. Rockfall simulation methods have been developed for countermeasures against rockfall.

Here, we present the present status of rockfall simulation, characteristic values to specify rockfall movement, and an outline of the analysis software.

4.7.1 Methodology

a. Present status of rockfall simulation

Ritchie (1963) in the U. S. was the first researcher to propose a method for estimating the falling paths and speeds of rocks that fall along a slope. For the sake of convenience, he assumed movement forms for three basic slope gradients (Figure 4.7.1).

His method "(1) considers the damping of energy and velocity component at the time of collision of fallen rocks by the size and (2) applies them to common slopes, where different slope gradients are combined."

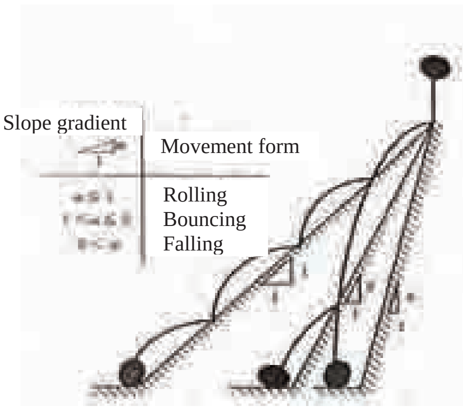


Figure 4.7.1 Ritchie's Fall Models

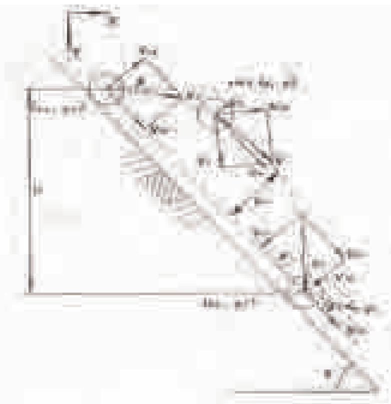


Figure 4.7.2 Bouncing and Collisions of Fallen rocks

The basic forms of rockfall movement on a slope can be classified into (1) sliding, (2) rolling (collectively called linear movement), and (3) bouncing (i.e., falling in the air and bouncing).

However, movement of falling rocks is not simple. Rocks commonly fall in combinations of these movements, depending on the form and size of the falling rocks, lithology, and state of vegetation.

Simulation methods for estimating the behavior of falling rocks on a complex slope have been developed in various countries. Those methods have been developed based on the motion equation of movement types of rockfall (i.e., sliding, rotation, and bouncing) and by considering the friction between the slope and falling rocks, loss and attenuation of the energy of falling rocks when they collide with the slope.

In Japan, the Monte Carlo simulation method has been adopted which is that parameters of rockfall simulation are derived from the theory of probability based on past rockfall tests.

b. Parameters to specify rockfall movement

To accurately simulate or predict rockfall movement on a slope, various coefficients and parameters that may influence the motion behavior of rockfall are selected by referring to past test data.

Provided that these coefficients have a normal distribution random numbers are generated from the confidence limit (95% confidence interval), and various constants are determined and used for the simulation. Based on test results, an equivalent friction coefficients corresponding to the type of slope (Table 4.7.1) are used to obtain the kinetic energy (considering 10% rotational energy) of falling rocks in a simplified manner.

Dr. Spang's rockfall simulation (Spang, 1987; Spang, 1998) specifies parameters by the state of slope: friction angles (dynamic, static), damping factors (normal, tangential), rolling resistance, and roughness of the slope (amplitude, frequency), as listed in Table 4.7.2. The parameters and their fluctuation ranges (%) are set as initial conditions for the simulation.

Table 4.7.1 Classification of Slopes and μ (equivalent friction coefficient) value

Classification	Characteristics of rockfall and slope	Range of μ	μ used for design
A	Hard rock, round rocks, low roughness, no wood	0.0 to 0.1	0.05
B	Soft rock, angular to round rocks, medium to high roughness, no wood	0.11 to 0.20	0.15
C	Sediment, talus cone, round to angular rocks, small to medium roughness, no wood	0.21to 0.30	0.25
D	Talus cone, (talus cone containing large rocks), angular rocks, medium to high roughness, no wood to some wood	0.31 to 0.60	0.31～0.40

Table 4.7.2 Dr. Spang's Version – Parameter Selection Table for Rockfall Simulation

Surface Type	Friction Angle		Damping Factors		Rolling resistance Rw	Roughness	
	Dynamic Rg (deg)	Static Rh (deg)	Normal Dn	Tangential Dt		Amp. Oa (m)	Freq. Of (m)
(1) Rock with mainly smooth surface	29 to 32	38 to 42	0.05 to 0.07	0.86 to 1.00	0.02	0.10	1.00
(2) Rock with rough surface	29 to 32	38 to 42	0.05 to 0.07	0.86 to 1.00	0.04 to 0.06	1.00	2.00
(3) Rock debris covered with wood	25	33 to 37	0.04 to 0.06	0.81 to 0.99	0.07 to 0.09	0.50	1.00
(4) Rock covered with a thin soil layer	14 to 16	29 to 32	0.03 to 0.04	0.72 to 0.88	0.09 to 0.12	0.20	1.00
(5) Rock debris covered with a thin soil layer	14 to 16	33 to 37	0.03 to 0.05	0.77 to 0.94	0.13 to 0.17	1.00	1.00
(6)Residual soil covered with grass	14 to 16	29 to 32	0.03	0.68 to 0.82	0.10 to 0.14	0.05	1.00

c. Dr. Spang's version of rockfall movement simulation

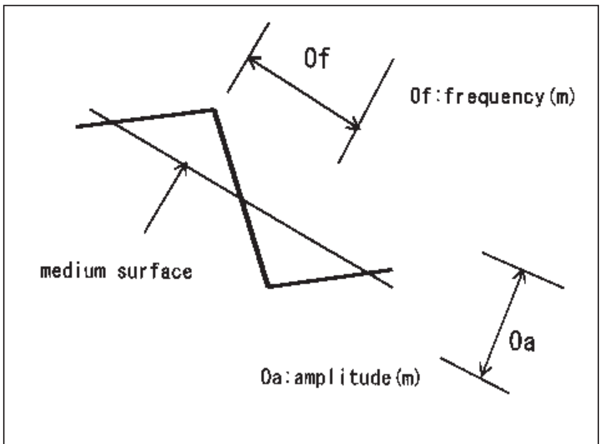
We use the rockfall simulation software developed by Dr. Spang et al., which is used in designing countermeasures against rockfall in European countries (e.g., Germany, Austria, and Switzerland).

c.1 Software: ROCKFALL 7.1

- We use the rockfall simulation software developed by Dr. Spang et al., Geoplan GmbH, Germany.
- This program has the basic function of calculating the paths of rolling, slipping, colliding, and bouncing based on Newton's laws of motion as well as changing in angular momentum that occur in rolling motions and collisions.
- It is possible to set parameters (e.g. friction angle, damping factor, rolling resistance, and slight roughness of the slope) arbitrarily by surface type.
- As calculation results, kinetic energy and bounce height of rocks on the whole slope is depicted as envelope curves. When the proposed countermeasures are set, the kinetic energy and bounce height (vertical height) of fallen rocks at such positions is displayed as statistical values.

c.2 Setting initial conditions for simulation

- As basic parameters for the rockfall simulation, friction angles (dynamic, static), damping factors (normal, tangential), rolling resistance, and roughness of the slope (amplitude, frequency) according to surface type are in the software.
- Friction angles and damping factors are proposed based on the results of rockfall tests conducted in Switzerland. The rolling resistance is estimated from Rosenheusen's definition (1978).
- Parameters and their fluctuation ranges (%) can be set as the initial conditions for simulation. The range of the rockfall area the fallen rock's radius can also be set.
- Either spherical or cylindrical falling rocks can be selected.
- Free fall or sliding/rotation can be selected as the initial movement of rockfall. Furthermore, when analyzing countermeasures against earthquakes, an arbitrary initial velocity corresponding to the horizontal acceleration of the earthquake can be set.
- A characteristic initial condition is that fine deviations of the slope surface can be set as the amplitude and frequency of the slope roughness.
- The fine deviations on actual slopes significantly influence rockfall movement.



How to give amplitude and frequency

Figure 4.7.3 Roughness of the Slope: How to Give Amplitude and Frequency

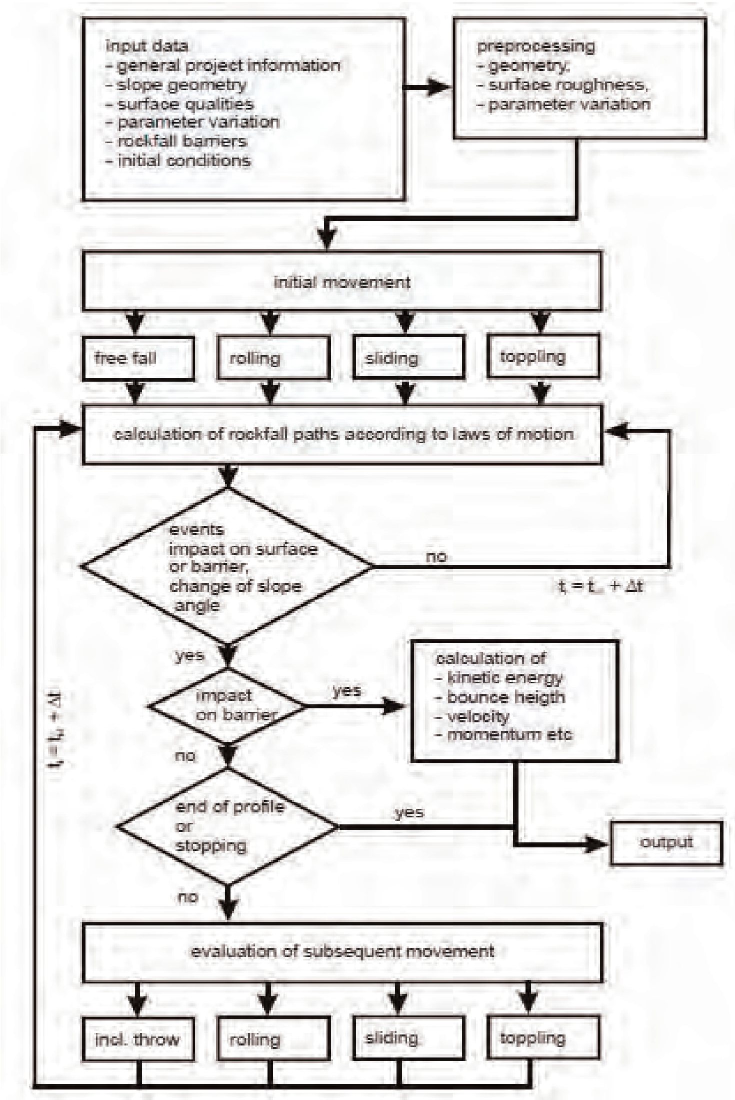


Figure 4.7.4 Rockfall Movement Simulation by Dr. Spang

4.7.2 Rockfall Interpretation

a. Definition of rockfall

Rockfall occurs when rocks and detritus separate a slope due to expansion of cracks (e.g., joint, schistosity, and layer) in the bedrock. Rockfall may also occur when gravels in the colluvial deposit, volcanic material, and sand/gravel layer with less consolidation come up to the surface by the matrix weathering.

b. Forms of rockfall

Figure 4.7.5 depicts common relationships between the topography/geology and the movement type and landform of the rockfall source. Rockfall can be classified into "fall-off type" and "exfoliating type" in this Report, depending on the movement type at the source.

The movement type at the rockfall source depends on the geological conditions of the slope. The fall-off type of rockfall occurs when (1) the softer matrix is weathered selectively, (2) gravels which are embedded in a slope come up to the surface, and then (3) they fall. Matrix around the embedded gravels is eroded by rainfall, triggering this type of rockfall.

The exfoliating type of rockfall is composed of the following two types. The one occurs gravels flake off from rock cracks (e.g., joint, schistosity, and layer) on rock slope. The another occurs when (1) a soft portion is weathered and eroded selectively in a stratus where hard and soft layers alternate, (2) the hard portion overhangs, and (3) the overhung portion breaks and falls.

In the Abay area, rockfall take the types of (1), (6), (7), and (8) in Figure 4.7.5.

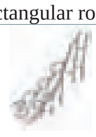
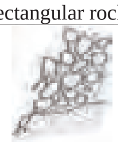
Fall-off type	(1) Floating and falling of rocks out of the talus deposit that composes a steep slope of talus and the cutout face of talus.	(2) Floating and falling of rocks out of the terrace layer that composes riverside and coast terrace cliffs and the cutout surface of terraces.	(3) Floating and falling of rocks out of the steep slopes and cutout faces slopes consisting of vulnerable conglomerate, or deposit of pyroclastic flow, and volcano mud flow.	(4) Floating and falling of non-weathered gravels in slopes due to weathering of granite and hard rock.
	Semi-rectangular rocks to rectangular rocks	Rounded rocks to semi-rounded rocks	Rounded rocks to rectangular rocks	Rounded rocks to semi-rectangular rocks
				
Exfoliating type	(5) Sliding down along the bedding plane or schistosity plane of bedrock with developed layers or schistosity that composes a dip slope.	(6) Exfoliating off from bedrock with developed three direction cracks and falling from the fracture plane.	(7) Slide down from steep bedrock with the developed columnar joints.	(8) Breaking and falling of the hard layers which overhung due to selective erosion.
	Massive to flat	Massive to flat	Massive	Massive
	Slate, shale, and schist and alternate layers of these and other rocks.	Plutonic rock such as granite, sandstone, schalstein, and sedimentary rock such as limestone, and fault fracture zones.	Basalt, lava such as andesite, and welded tuff, which have developed joints.	Alternative layers that are extremely different in harnesses.
				

Figure 4.7.5 Topography/Geology and Rockfall Type

c. Conditions for rockfall

The occurrence of rockfall has no premonitory phenomenon, and no correlation with events considered to be causes of rockfall has been clarified. Therefore, it is difficult to predict rockfall and to prevent rockfall disasters based on movement restrictions like a landslide. However, rockfall does exhibit characteristic types, depending on the topographical and geological conditions of where it occurs. Thus, risky rockfall locations can be specified by investigating basic factors and inducing factors of rockfall, state of the slope, and disaster records. It is therefore possible to roughly estimate the size, form, and movement of rockfall.

In the Abay area, several locations where rockfall frequently occurred are identified, based on records of past disasters. They are the area where the landslide areas and steep slopes on the upward side of Filiklik Village (ST.0 to ST.5+900), the plateau skirt around Abay River (ST.16+700 to ST.21+400), and the steep slope and cut slope on the Dejen side (ST.30+500 to ST.35+600).

Table 4.7.3 Location of Disaster(Rockfall) during Rainy season in 2010

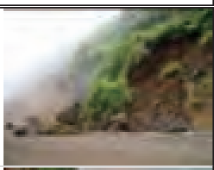
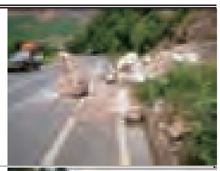
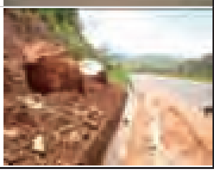
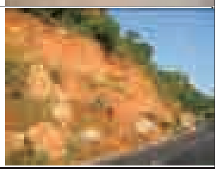
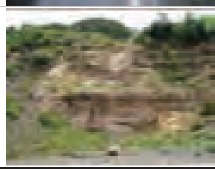
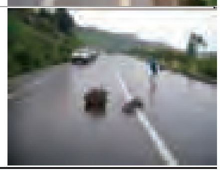
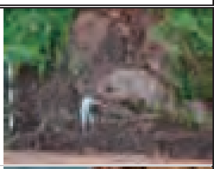
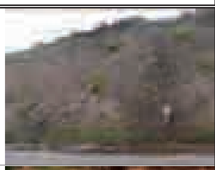
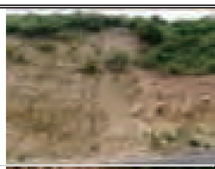
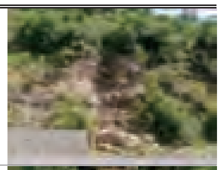
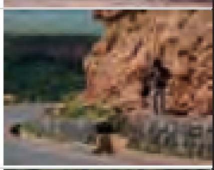
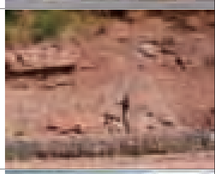
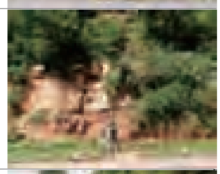
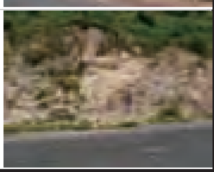
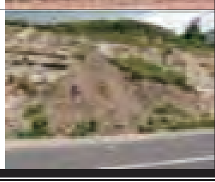
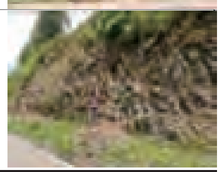
ST. No	Photo of rockfall Rain season in 2010	ST. No	Photo of rockfall Rain season in 2010	ST. No	Photo of rockfall Rain season in 2010	ST. No	Photo of rockfall Rain season in 2010
1+ 000		1+ 500		17+ 300		20+ 300	
20+ 690		20+ 740		30+ 650		30+ 960	

Table 4.7.4 Location of Disaster(Rockfall) during Rainy season in 2011

ST. No	Photo of rockfall Rain season in 2011	ST. No	Photo of rockfall Rain season in 2011	ST. No	Photo of rockfall Rain season in 2011	ST. No	Photo of rockfall Rain season in 2011
0+ 930		2+ 510		6+ 680		14+ 60	
17+ 890		18+ 740		20+ 260		20+ 820	
30+ 600		32+ 370		34+ 420		35+ 560	

d. Basic factor and inducing factor of rockfall

d.1 Basic factor

Topographical and geological conditions have been cited as basic factors of rockfall.

A steep slope is a landform that easily causes rockfall. Also, rockfall commonly occurs when a slope is overhanging.

As for geology, a fall-off type rockfall easily occur where matrix around gravels is easily weathered and eroded in terrace conglomerate layer, pyroclastic sediment, and weathering rocks. An exfoliating type rockfall commonly occurs when the rocks surrounded by cracks developing in the bedrock are floating.

Figure 4.7.6 depicts a schematic diagram of a natural slope. Rockfall occurs most frequently in the steep slope in the central part. The frequency of rockfall is low in the upper and lower parts of the slope. However, rockfall may occur even at the foot of a mountain if cutting is performed or a gully is formed due to concentration of water. Similarly, if erosion has advanced and the slope is steep up to the ridge, rockfall may occur even in the upper part.

Whether a rockfall disaster occurs or not depends on the condition of the bottom of the slope.

If falling rocks can be stopped before reaching the object being protected, the risk of a rockfall disaster is low. Conditions that help stop falling rocks include a flat ground surface, a gentle slope, a hollow, a bank, and a rockfall protection wall.

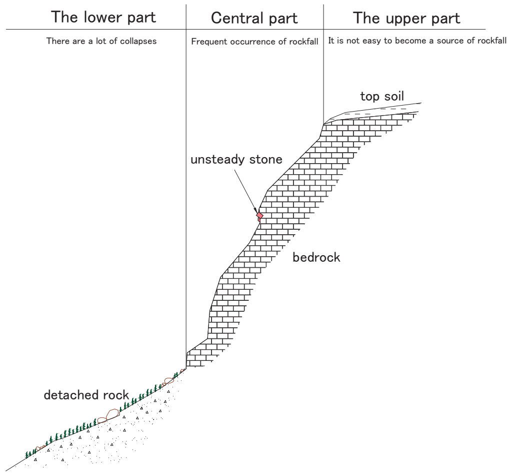


Figure 4.7.6 Form of the Slope and Rockfall

d.2 Inducing factor

Rainfall, wind, earthquake, and artificial matters are inducing factors of rockfall. However, it is difficult to determine the inducing factor of rockfall.

Rockfall occurs even when continuous precipitation and/ or rainfall intensity is small. Therefore, occurrence of rockfall correlates weakly with precipitation. However, there are data that rockfall increases when the rainfall intensity is 30 to 40mm/h.

4.7.3 Analysis result

Rockfall simulation is implemented in locations where the risk of rockfall is high or rockfall disasters were observed in the past.

a. Cross sections to be examined

Conditions for setting rockfall simulations are listed in Table 4.7.5. They include cross sections to analyze, the location of the rockfall source, and the size of the rockfall. The diameters of rocks observed near the cross section to be analyzed are used. The falling rocks are assumed to be spherical, and the density of rock is assumed to be 2.5 t/m^3.

Table 4.7.5 Cross Sections to be Examined and the Size of Rockfall in Rockfall Simulation

Section	Cross section to analyze	Location of the source of rockfall	Diameter of falling rocks ϕ (m)	Mass of rockfall m (kg)	Remarks
RF02-1	Section 6 (ST.2+400)	Source of rockfall (H = 25.0m)	0.3 ±0.1	35.3 ±3.5	Rockfall from the upper portion of the cut slope (Initial movement: Rolling)
RF05-1	Section 15 (ST.5+480)	Source of rockfall (H = 18.8m)	1.3 ±0.1	2874.4 ±67.0	Rockfall from the hillside of the slope (Initial movement: Free fall)
RF16-1	Section 28 (ST.17+630)	Source of rockfall (H = 80.4m)	1.4 ±0.2	3590.1 ±155.0	Rockfall from the top of the slope (Initial movement: Free fall)
RF20-3	Section 46 (ST.21+000)	Source of rockfall (H = 45.5m)	1.5 ±0.2	4415.6 ±175.0	Rockfall from the upper portion of the slope (Initial movement: Rolling)
RF34-1	Section 50 (ST.34+380)	Source of rockfall (H = 18.9m)	0.7 ±0.1	448.8 ±19.5	Rockfall from the upper portion of the slope (Initial movement: Rolling)

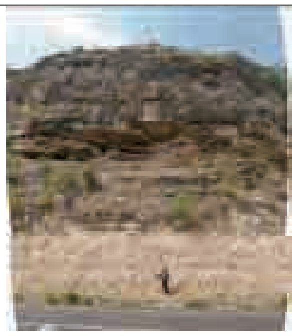
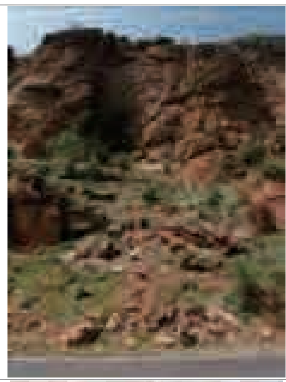
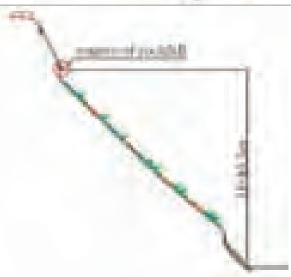
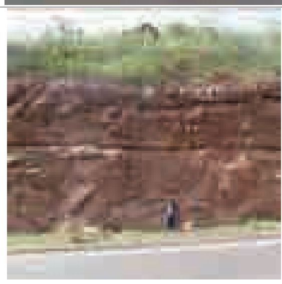
b. Parameters selected for rockfall simulation

Parameters such as the friction angle, rolling resistance, and roughness of the slope for each slope are listed in Table 4.7.6. In case the analysis results do not match the actual state of rockfall at the site, the parameters should be reviewed.

Table 4.7.6 Parameters Selected for Rockfall Simulation

Surface Type	Friction Angle		Damping Factors		Rolling resistance Rw	Roughness	
	Dynamic Rg(deg)	Static Rh(deg)	Normal Dn	Tangential Dt		Amp. Oa(m)	Freq. Of(m)
(1) Rock with mainly smooth surface	30	40	0.06	0.93	0.02	0.10	1.00
(2) Rock with rough surface	30	40	0.06	0.93	0.05	1.00	2.00
(3) Rock debris covered with wood	25	35	0.05	0.9	0.08	0.50	1.00
(4) Rock covered with a thin soil layer	15	30	0.035	0.8	0.10	0.20	1.00
(5) Rock debris covered with a thin soil layer	15	35	0.04	0.85	0.15	1.00	1.00
(6)Residual soil covered with grass	15	30	0.03	0.75	0.12	0.05	1.00

Table 4.7.7 Locations to be Examined in Rockfall Simulation

Cross section to analyze, rockfall conditions	Cross section	Rockfall slope	Remarks
Section 6 (ST.2+400) Source of rockfall (H = 25.0m) Size of rockfall (0.3m)			On the cut slope with developed cracks, small rocks are scattering in the ditch and on the road.
Section 15 (ST.5+480) Source of rockfall (H = 18.8m) Size of rockfall (1.3m)			The upper portion of the slope is a natural slope while the lower portion is a cut slope. The lower face of the overhung portion has become unstable by developed cracks.
Section 28 (ST.17+630) Source of rockfall (H = 80.4m) Size of rockfall (1.4m)			The slope is high, and fallen rocks with a diameter of 1m are scattering in the lower portion of the slope.
Section 46 (ST.21+000) Source of rockfall (H = 45.5m) Size of rockfall (1.5m)			Vegetation grow thickly below the high risky rockfall area. There is a continuous cut slope on the roadside.
Section 50 (ST.34+380) Source of rockfall (H = 18.9m) Size of rockfall (0.7m)			This is a cut slope with advanced weathering, and rocks are scattered on the natural slope above the cut slope. Many rockfall disasters were observed in the past.

c. Results of rockfall simulation

The results of the rockfall simulation are presented in the Appendix. Results for Section 28, which has a high risk, are depicted in Figures.4.7.7 to 4.7.9. In the simulation, the kinetic energy and bounce height of the falling rocks at an arbitrary point can be obtained. The results presented below indicate the kinetic energy and bounce height of falling rocks on the boundary between the road and the end of the slope.

Table 4.7.8 Maximum Energy and Maximum Bounce Height on the Roadside in the Rockfall Simulation

Cross section to analyze	Location of the rockfall source	Diameter of falling rocks ϕ (m)	Mass of rockfall m(kg)	Rockfall Movement		Remarks
				Max. energy (kJ)	Max. bounce height (m)	
Section 6 (ST.2+400)	Source of rockfall (H = 25.0m)	0.3±0.1	35.3 ±3.5	12	3.54	Kinetic energy is small, but bounce height is great.
Section 15 (ST.5+480)	Source of rockfall (H = 18.8m)	1.3±0.1	2874.4 ±67.0	352	2.23	Bounce height is somewhat high.
Section 28 (ST.17+630)	Source of rockfall (H = 80.4m)	1.4±0.2	3590.1 ±155.0	1754	0.11	Kinetic energy is the greatest.
Section 46 (ST.21+000)	Source of rockfall (H = 45.5m)	1.5±0.2	4415.6 ±175.0	492	2.46	Bounce height is somewhat high.
Section 50 (ST.34+380)	Source of rockfall (H = 18.9m)	0.7±0.1	448.8 ±19.5	64	0.03	Bounce height is low.

In the rockfall simulation, defense facilities such as rockfall protection fences can also be input. The results are plotted in Figures 4.7.10 and 4.7.11.

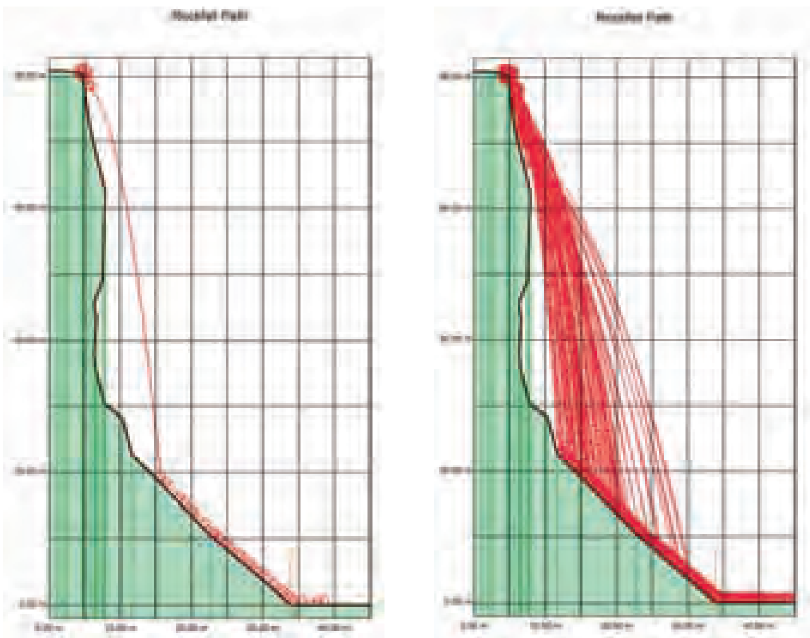


Figure 4.7.7 Rockfall Paths (Left: 5 fallen rocks. Right: 300 fallen rocks)

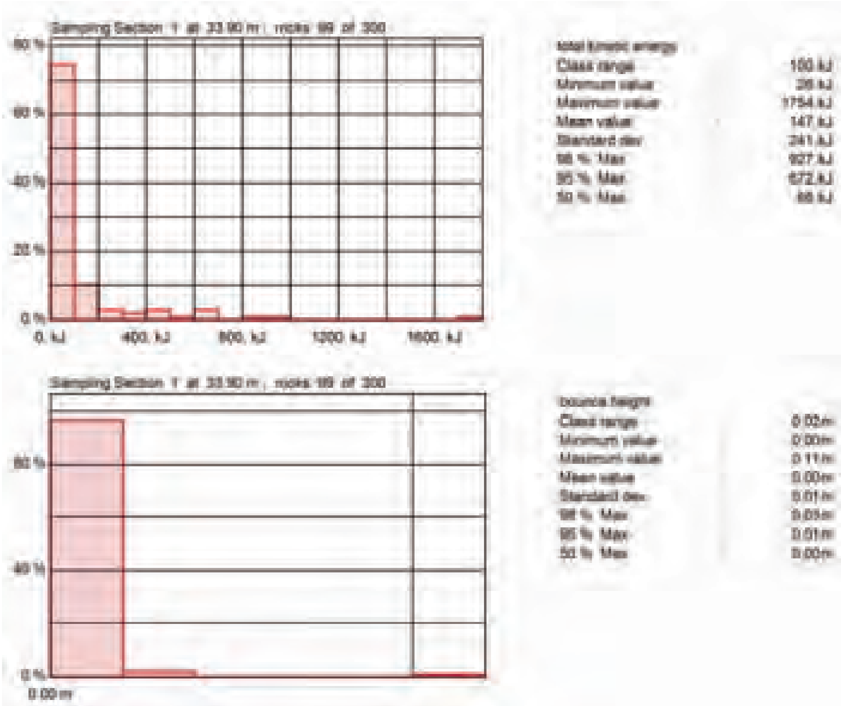


Figure 4.7.8 Kinetic Energy and Bounce Height at the Foot of the Slope (Top: Kinetic energy. Bottom: Bounce height.)

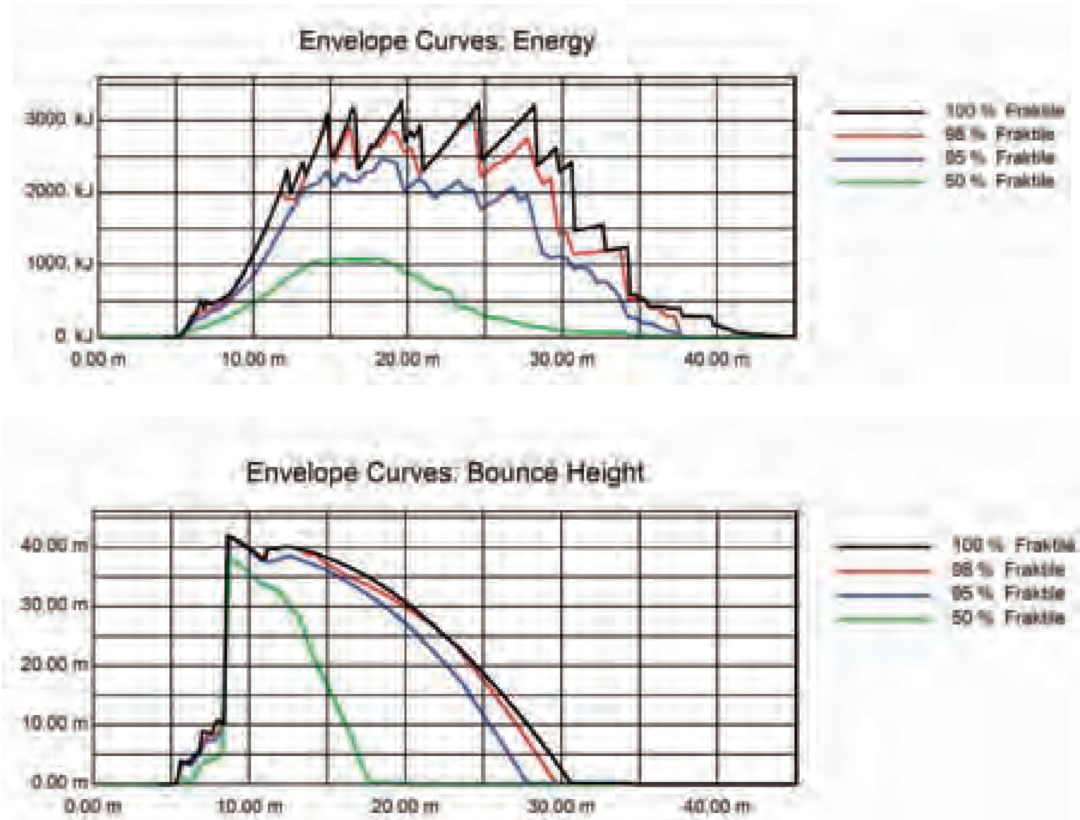
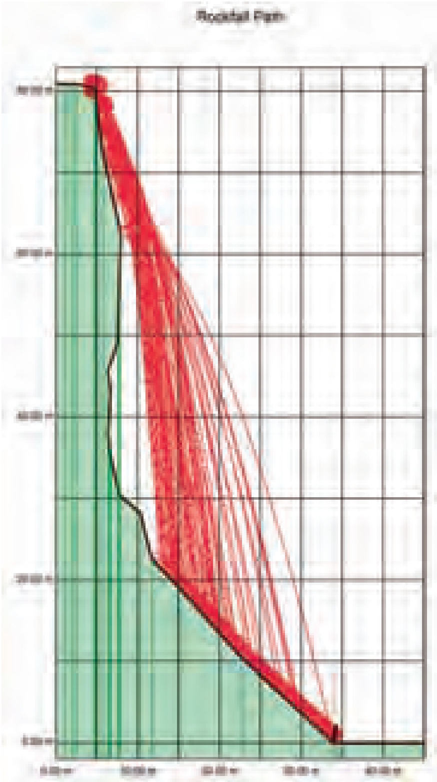
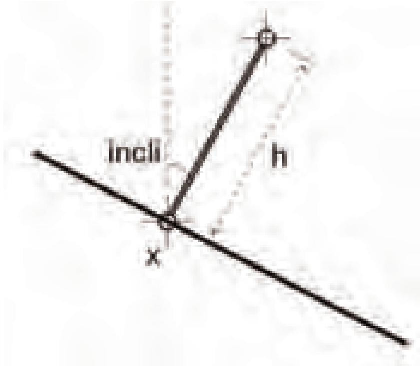


Figure 4.7.9 Changes in Kinetic Energy and Bounce Height (Top: Kinetic energy. Bottom: Bounce height.)

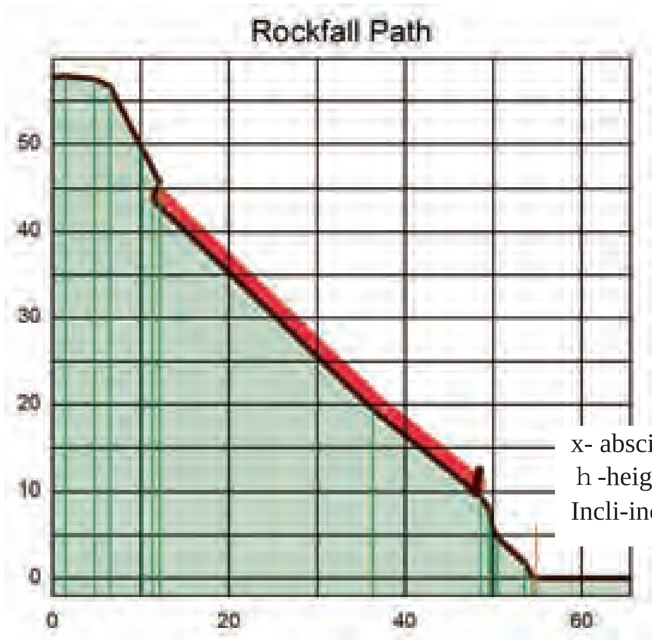




－Rockfall barriers－
x- abscissa of the base point in meters
h -height in meters
Incli-inclination, in degrees

x- abscissa of the base point in meters =33.9m
h -height in meters = 2.0m
Incli-inclination, in degrees =10°

Figure 4.7.10 Rockfall Paths with a Rockfall Protecting Fence Installed (Section 28)



x- abscissa of the base point in meters =48.0m
h -height in meters = 2.0m
Incli-inclination, in degrees =10°

Figure 4.7.11 Rockfall Paths with a Rockfall Protecting Fence Installed (Section 46)

4.8 Debris Flow Analysis

Numerical simulation of debris flow utilized to prepare hazard maps and examine effective sediment disaster management plans in drainage basins in mountainous area.

Here, we describe the present status of debris flow simulation, parameters to specify the movement of debris flow, and an outline of the analysis software.

4.8.1 Methodology

a. Present status of debris flow simulation

Debris flow is an intermediate dynamics which is solid-water phase flow consisting of dried solid particles and water. Its structure is quite complex. Although many researchers have proposed their original constitutive rules, no universal rule has yet been established. To verify the proposed constitutive rules under these circumstances, indoor experiments on the flowage and deposit of debris flow and numerical simulation are being conducted. Also, studies to enhance the universality of the rules and analysis models while comparing flow velocity, flow rate, sediment concentration, and sedimentary figure are being widely performed.

Debris flow simulation enables the simulation of the actual paths that debris fluid followed. Furthermore, it enables analysis of how the debris flow is controlled by such structures as sabo dams. Such simulation is also utilized to prepare hazard maps that indicate the flow down, flood, and sedimentation of debris flow. Thus, studies that lead to countermeasures for sediment disasters are currently being conducted.

b. Parameters to specify the movement of debris flow

Parameters of debris flow (e.g., flow velocity, flow rate, and sediment concentration) depend on (1) the longitudinal and cross-sectional forms of the river bed in the upper river basin, (2) longitudinal distribution of the thickness and distribution of particle sizes of deposit on the river bed, and (3) rainfall conditions. When a large volume of deposit exists on a steep slope, the slope can be eroded and incorporated into debris fluid, and debris flow can develop rapidly. On a gentle slope, materials in debris flow begin to sediment, and debris flow attenuates.

Debris flow simulation is expressed by the governing equation which tracks the process from the occurrence of debris flow to the end of sedimentation, and constitutive rules of the flow consisting of a mixture of sediment and water. The following parameters are required for analysis.

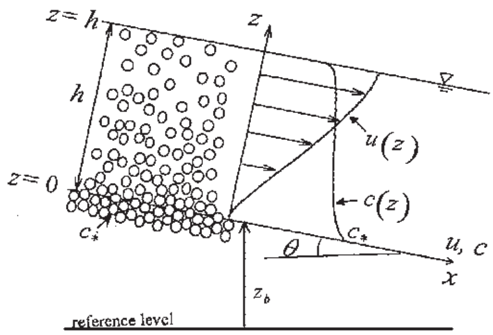


Figure 4.8.1 One-Dimensional Flow and Coordinate System

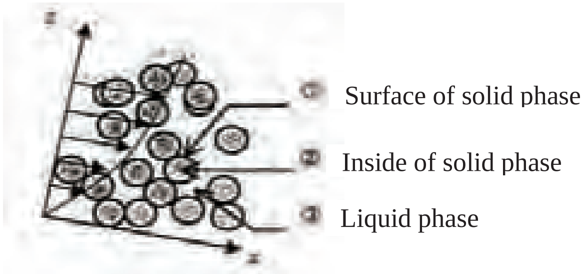


Figure 4.8.2 Schematic Diagram of Solid-Water Phase Flow

Table 4.8.1 Parameters Required for Debris Flow Simulation

Simulator model variable	Value	Simulator model variable	Value
Simulation continuance time (sec)	Set from time rainfall continues	Volumetric ratio of finer material in the bed	Set from rock size in the bed
Time interval of calculation (sec)	Do.	Gravity acceleration (m/s^2)	9.8
Number of particle grades	Default 2	Coefficient of erosion rate	Default 0.0007
Diameter of each grade particle (m)	Coarser material, finer material	Coefficient of deposit rate	Default 0.05
Mass density of bed materials (finer material)	Default 2650kg/m^3	Minimum depth at the front of debris flow (m)	Default 0.05
Mass density of fluid phase	Default 1100kg/m^3	Minimum flow depth (m)	Set from the state of the river bed
Concentration of movable bed	Default 0.65	Minimum concentration of material in the bed	Default 0
Internal friction angle	0.7 to 0.8	Manning's roughness coefficient	Set from the state of the river bed
Volumetric ratio of coarser materials in the bed	Set from gravel size in the bed	—	—

c. Debris flow simulation for one-dimensional calculation of river bed variation

We use "debris flow simulation for one-dimensional calculation of river bed variation," which was developed jointly by the SABO Technical Center in Japan and Kyoto University.

c.1 Software in use: Kanako Ver. 1.42

・ Conditions can be set easily

The initial river bed, thickness of river deposit material, river (topographical) data of river width, supplied hydrograph, and positions of facilities can be set easily.

・ Model that reflects the effect of facilities

The flow/deposit model for debris flow and the model to analyze the sediment control function of grid-type sabo dams are used. This method enables simulation of the flow/deposit process of debris flow consisting of two types, large and small particles, near the sabo dam, which was difficult to simulate in the past.

・ Enables calculating debris flow, tractional debris flow, and bed load transport.

Coarse grained debris flow is mainly addressed. When the debris flow becomes tractional debris flow or a bed load transport as the sediment concentration changes, automatic calculations are made continuously.

・ Three types of sabo dam

Ordinary impermeable sabo dams, slit sabo dams, and/or grid sabo dams can be installed in arbitrary positions on the river bed.

・ Input/output in text files

Common parameters such as the mass density of bed material and the time interval of calculation can be set in text files. Calculation results are output in the CSV format so that data can be read and converted with other applications, including MS EXCEL.

c.2 Constrained conditions

・ Calculations accommodate only one tributary stream. Confluence of tributary mountain streams is not considered.

・ Calculations accommodate only two grades of particle diameter.

・ Energy loss in permeable sabo dams due to rapid contraction of the slit section is not considered.

・ The cross section in the calculation is assumed to be rectangular.

・ The mechanism for the concentration of huge boulders in the front edge in a coarse grained debris flow is not incorporated.

・ Temporal and special changes in particle-size distribution on the river bed are not considered.

・There are 30 to 50 topographic data setting points and river bed evolution calculation points.

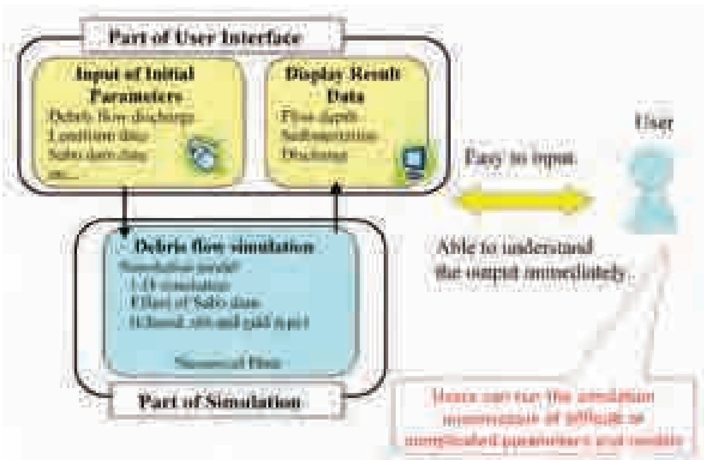


Figure 4.8.3 Schematic Diagram of the System

4.8.2 Debris flow Interpretation

a. Definition of debris flow

Debris flow is a phenomenon of the flowing down of sediment and rocks saturated with water. Debris flow occurs when a large volume of water is supplied to the valley of a steep slope where sediment is accumulating.

b. Types and triggers of debris flow

Types of debris flow include (1) flow-in of sediment due to hillside failure and (2) liquefaction of sediment on the stream bed. With the former, hillside failure occurs, and collapsed soil changes into debris flow (some debris flows are caused by landslides). The amount of rainfall and the sediment materials on the stream bed are also related to the occurrence of debris flow. With the latter, the slope of the stream bed, the drainage area, and the state of the stream bed are largely involved. Triggers of debris flows include heavy rain, snow melting, earthquake, and volcano eruption. Debris flows in the Abay area are caused by heavy rain.

c. Current states of debris flows

It is highly probable that debris flow occur when heavy rain occurs after continuous rainfall. The amount of rainfall (mm per hour) that causes a debris flow varies from one site to another. Based on the interviews and site investigations, debris flow and sediment runoff are frequently observed in Filiklik and Kurar specifically after continuous rainfall and when precipitation reaches 40 mm per hour.

Photo 4.8.1 Overflowed sediment at S08-2

Photo 4.8.2 Overflowed sediment at S09-1

Photo 4.8.3 At the confluence of S30-2and 30-3

Photo 4.8.4 Overflowed sediment at S31-2

Moreover, surface runoff occur along the walking path transporting road based gravels and debris downstream indicating that these walking roads can also be pathways for surface runoff.

Photo 4.8.5 Sediment runoff near ST.10+250

Photo 4.8.6 Sediment runoff near ST.32+800

d. Mechanism of the occurrence of debris flow

Based on general debris flow disasters, debris flow occurs frequently at sites where the slope of the stream bed is 20° or greater. In contrast, when the slope of the stream bed is 10° or less, sediment carried by debris flow begins to deposit. Debris flow occurs frequently in basins like small valley where a drainage area of 1 km² or less. The sediment yield produced by debris flow is usually 10,000m³ or less.

When debris flow occurs, most of the sediment deposited on the stream bed erodes and flows out with the water supplied after the debris flow. The erosion depth (thickness of sediment on the stream bed) is 1 to 2m, regardless of geology.

In the Abay area, unstable sediment on the stream bed, colluvial soil on the foothill, and colluvial sediment in the landslide area flowed out due to rainfall.

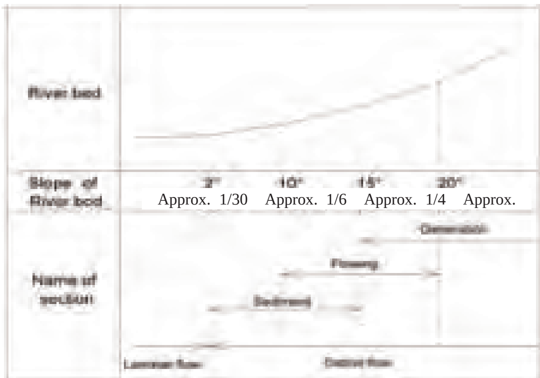


Figure 4.8.4 Guidelines of Sediment Movement Produced by the Slope of the Stream Bed

Photo 4.8.7 Unstable Sediment Deposited on the Stream Bed

Photo 4.8.8 Colluvial deposits at the base of plateau

Photo 4.8.9 Path of debris flow

4.8.3 Analysis result

Debris flow simulation is implemented for streams that have a high risk of debris flow or where debris flow damage occurred in the past.

a. Cross sections to be examined

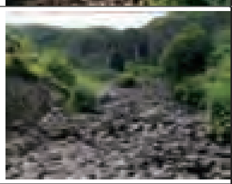
Conditions of the cross sections to be examined in the debris flow simulation (characteristics of the basin, particle diameter, volumetric ratio of particle diameters, and sediment concentration) are listed in Table 4.8.2.

Sediment concentration is assumed to be constant.

Table 4.8.2 Cross Section to be Examined in Debris Flow Simulation

Cross section	Characteristics of the basin				Particle diameter (m)		Sediment concentration (Max., Min.)
	Basin area (km^2)	Length of stream (m)	River width (m)	Slope of stream bed (°)	Max. (Volumetric ratio)	Min. (Volumetric ratio)	
S30-2 (ST.30+420)	0.059	600	1.5～6.0	15.3	0.5 (50%)	0.1 (50%)	0.3,0.15
S31-2 (ST.31+580)	0.018	500	2.0～20.0	16.0	0.7 (70%)	0.1 (30%)	0.3,0.15

Table 4.8.3 Field notes at planned target sites for debris flow simulation

Section	Streambed	Cross-drainage structures	Sediment-runoff	Notes
S30-2				Sediment runoff transported downstream into cropland & houses
S31-2				Sediment runoff occurred in 2008

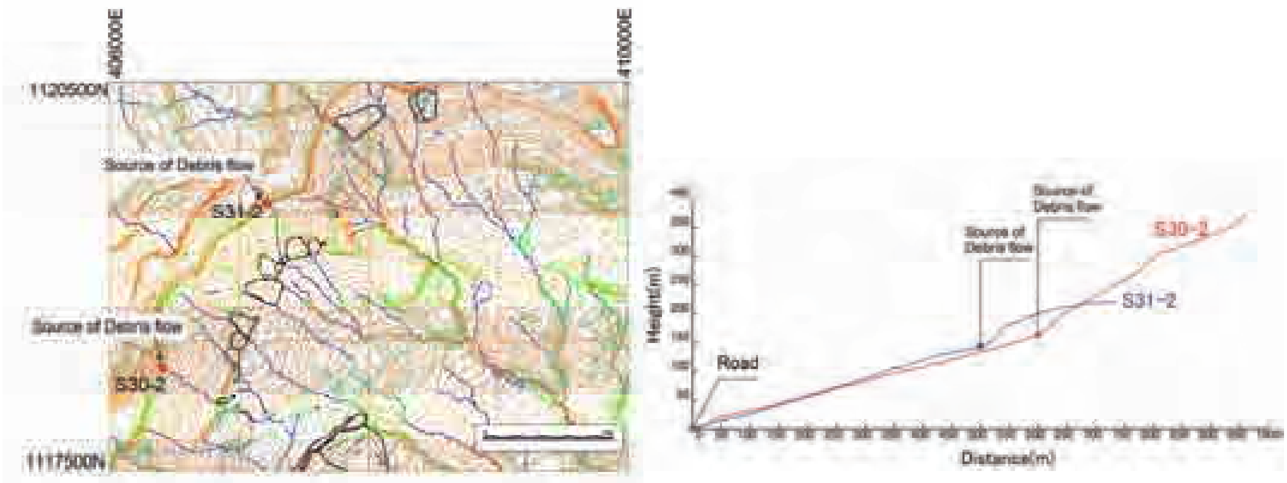


Figure 4.8.5 Locations and configurations of planned stream cross sections

b. Model variables for debris flow simulation

The parameters listed below were selected for model variables used in the debris flow simulation. In case the analysis results do not match the actual state of debris flow at the site the parameters should be reviewed.

Table 4.8.4 Parameters Selected for Debris Flow Simulation

Simulator model variable	Adopted value	Simulator model variable	Adopted value
Simulation continuance time	10800sec	Gravity acceleration	9.8
Time interval of calculation	0.01sec	Coefficient of erosion rate	0.0007
Mass density of bed material (finer material)	2650kg/m^3	Coefficient of deposit rate	0.05
Mass density of fluid phase	1100kg/m^3	Minimum depth at the front of debris flow (m)	0.05
Concentration of movable bed	0.65	Minimum concentration of material in the bed	0kg/m^3
Internal friction angle	0.7 (35°)	Manning's roughness coefficient	0.03

c. Setting of supplied hydrograph

c.1 Hyetograph and hydrograph

A hyetograph depicts rainfall distribution. This graph is prepared by referring to the rainfall distribution near the target site and that during disasters. A sediment disaster management plan usually addresses the rainfall for 100 years probability. Therefore, the rainfall for 100 years probability, instead of the total rainfall, is used as the planning rainfall.

A hydrograph depicts the relationship between flow discharge and time. This value is used in the debris flow simulation. To obtain discharge volume, rainfall is converted into flow discharge using the following equation:

$$Q = 1/3.6 \times f \times r \times A,$$

where Q : the planning flood discharge (m^3/s),

f: the coefficient of discharge

r : the intensity of rainfall(mm/h)

A: the catchment area(km^2).

Figure 4.8.6 depicts hourly rainfall by the rain gauge on days with a daily rainfall of 20mm or more. The duration of rainfall in the Abay area is 3 to 6h, and the rainfall distribution is triangular.

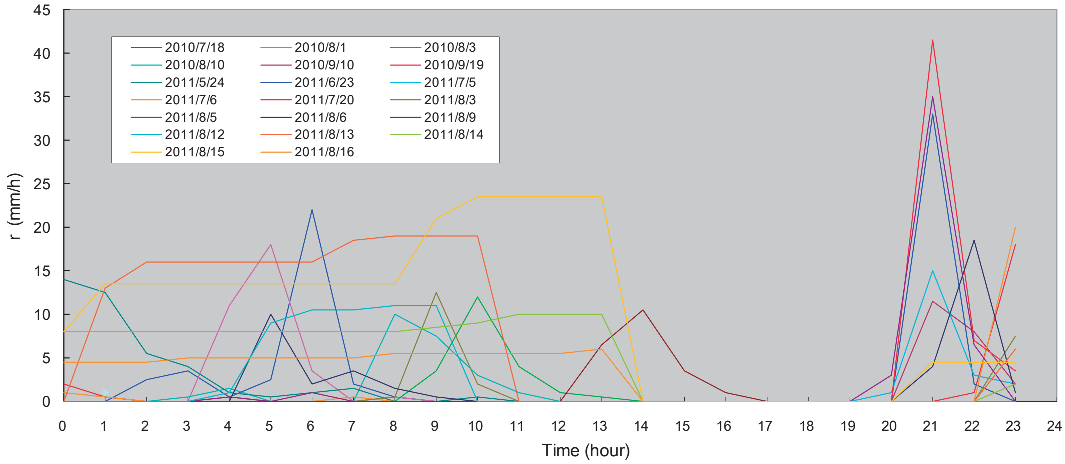


Figure 4.8.6 Hyetograph (hourly rainfall on days with a daily rainfall of 20mm or more)

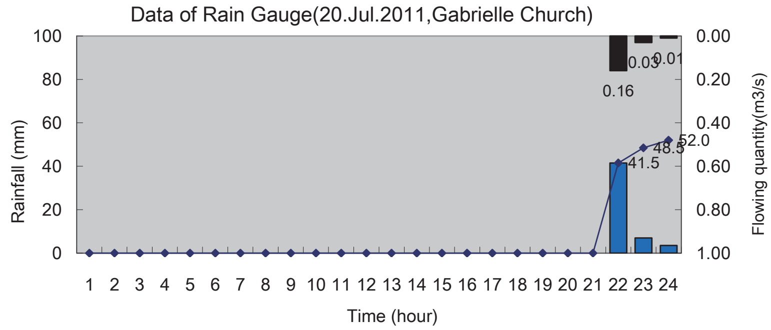
c.2 Supplied hydrograph

Values of supplied hydrograph should be flow discharge which can be calculated using rainfall data obtained from either weather stations or rain gages. It is preferred if hourly rainfall data during the past debris flow is available. We used data collected when a debris flow occurred on July 20, 2011. Figure 4.8.7 shows flow discharge at Gabrielle Church.

Table 4.8.5 Hydrograph where rainfall data during sediment discharge is corrected according to rainfall characteristics (S31-2)

Time	Rainfall per hour (mm/h)	Cumulative rainfall (mm)	Flow discharge Q (m^3)	Conditions
1	0	0	0	$Q = 1/3.6 \times 0.75 \times r \times 0.018(m^3)$ Duration of rainfall is set to 4h according to rainfall per hour observed in the district. Cumulative rainfall is set to the rainfall per day on July 20, 2011. Distribution of rainfall is assumed to be triangular.
2	41.5	41.5	0.16	
3	7.0	48.5	0.03	
4	3.5	52.0	0.01	

Time (hour)	Amount of rainfall(mm/h)	Discharge (m3/s)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
22	41.5	0.16
23	7.0	0.03
24	3.5	0.01



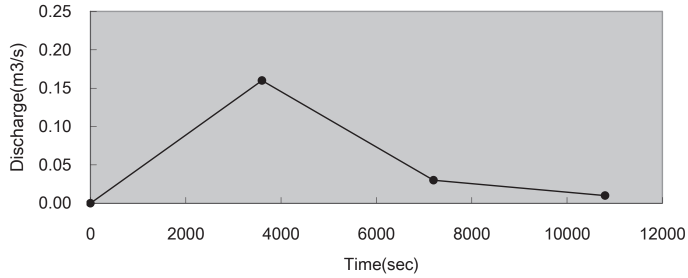


Figure 4.8.7 Hyetograph and Hydrograph During Debris Flow (S31-2)

d. Results of debris flow simulation

The results of the debris flow simulation are presented in Table 4.8.6. Using this simulation, the flow discharge and/or volume of sediment movement at an arbitrary point can be obtained.

The results indicate the thickness of deposit and volume of sediment that flows into cross-drainage work under the road.

The thickness of deposit is obtained by that the volume of sediment divided by the river width and length for the calculation. Sometimes it actually flows out in flood.

Table 4.8.6 Examination Results in Debris Flow Simulation

Cross section	Parameters of the basin				Cross-drainage work		Calculation result	
	Basin area (km^2)	Length of stream (m)	River width (m)	Slope of stream bed (°)	Width (m)	Height (m)	Volume of sediment (m^3)	Thickness of deposit (m)
S30-2	0.059	600	1.5～6.0	15.3	2.0	1.0	90.6	2.26
S31-2	0.018	500	2.0～20.0	16.0	3.0	1.5	104.5	1.74

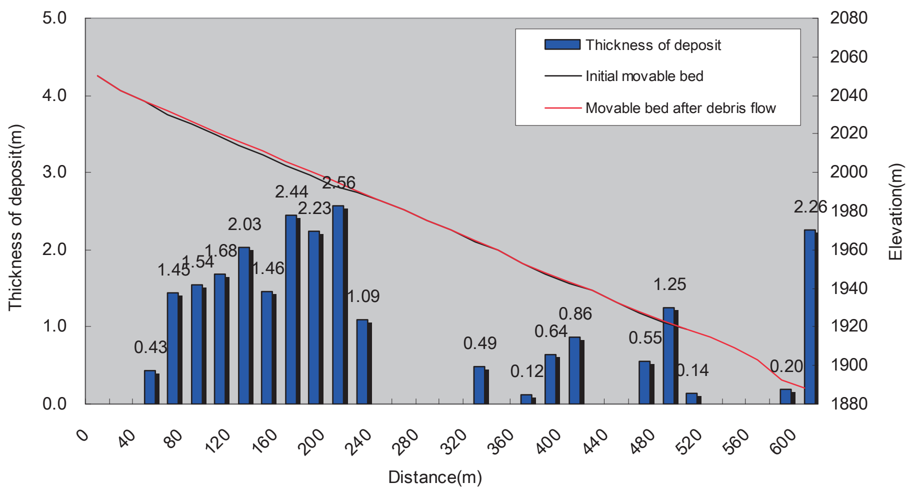


Figure 4.8.8 Relationship between Bed Variation and Thickness of Deposit (S30-2)

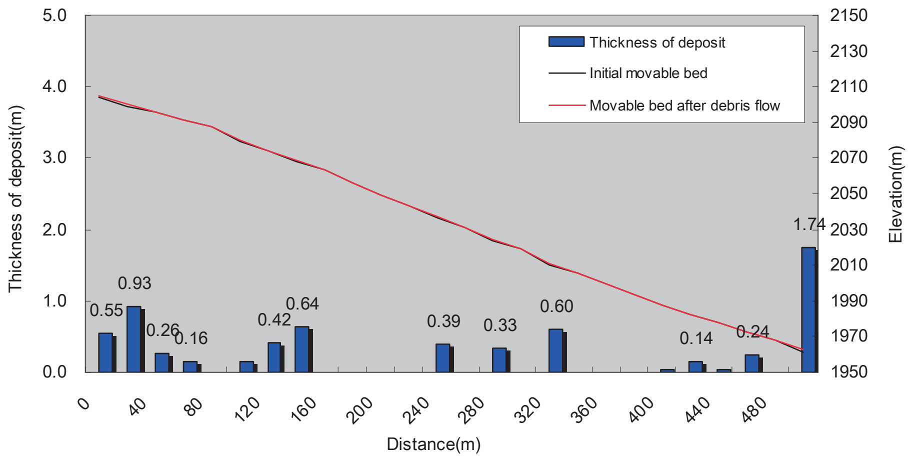


Figure 4.8.9 Relationship between Bed Variation and Thickness of Deposit (S31-2)

Debris flow countermeasure facilities (e.g., sabo dams) can be input in the debris flow simulation. Figures 4.8.11 and 4.8.12 depict the results.

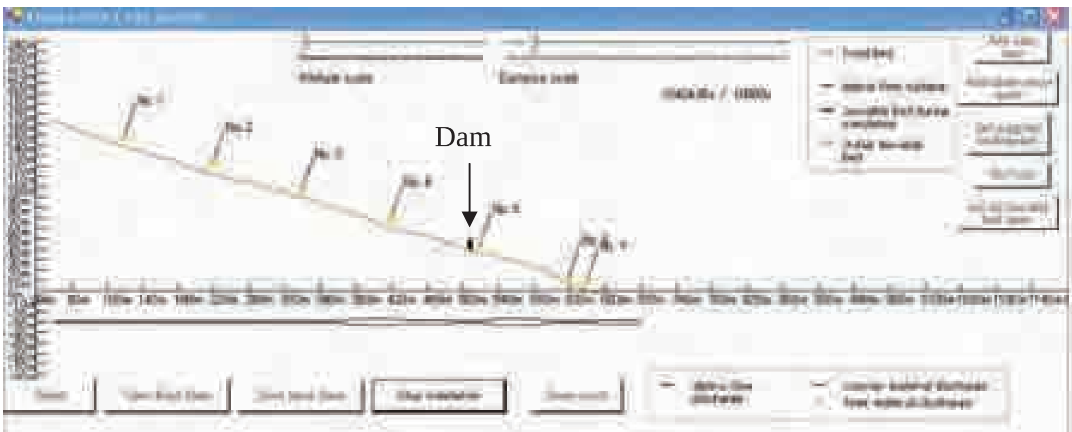


Figure 4.8.10 Screen of Kanako when a dam is added

By adding dams, debris and sediment transported downstream can be prevented.

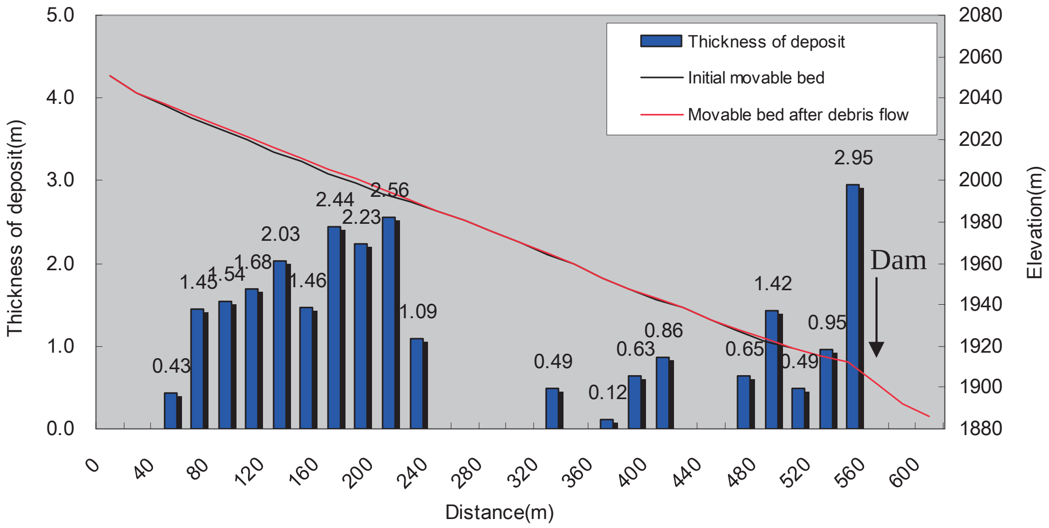


Figure 4.8.11 Changes in streambed and amount of sedimentation when a dam is installed (S30-2)

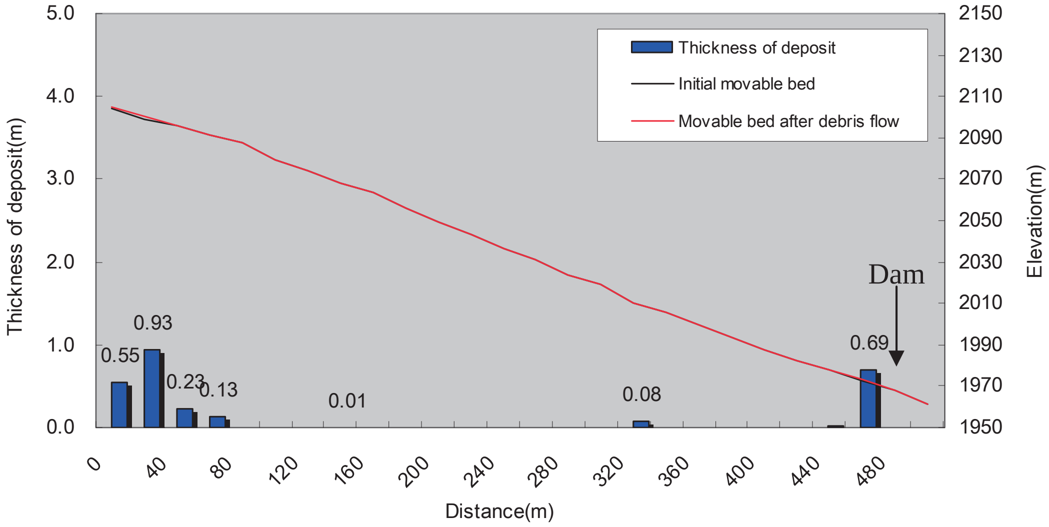


Figure 4.8.12 Changes in streambed and amount of sedimentation when a dam is installed (S31-2)

Chapter 5

Landslide Countermeasure

5 Landslide Countermeasure

5.1 General countermeasure for landslide

Landslide countermeasure is divided into control works and restraint works. The control work indirectly affects landslide risk by removing factors contributing to the slide; restraint work directly affects the landslide risk by countering against the driving forces.

The types of landslide countermeasure are shown in Figure 5.1.1 and Figure 5.1.2.

- Landslide countermeasures
  - Control works
    - Surface drainage work — Channel, Infiltration prevention
    - Shallow groundwater control work — Culvert, horizontal drainage boring
    - Deep groundwater control work — Horizontal gravity drain work, Drainage well, Drainage tunnel
    - Earth removal work
    - Buttress fill work — Slope protection work
    - Erosion prevention work
  - Restraint works
    - Piles
    - Large diameter cast-in-place shafts (deep foundation)
    - Anchors

Figure 5.1.1 Landslide countermeasures

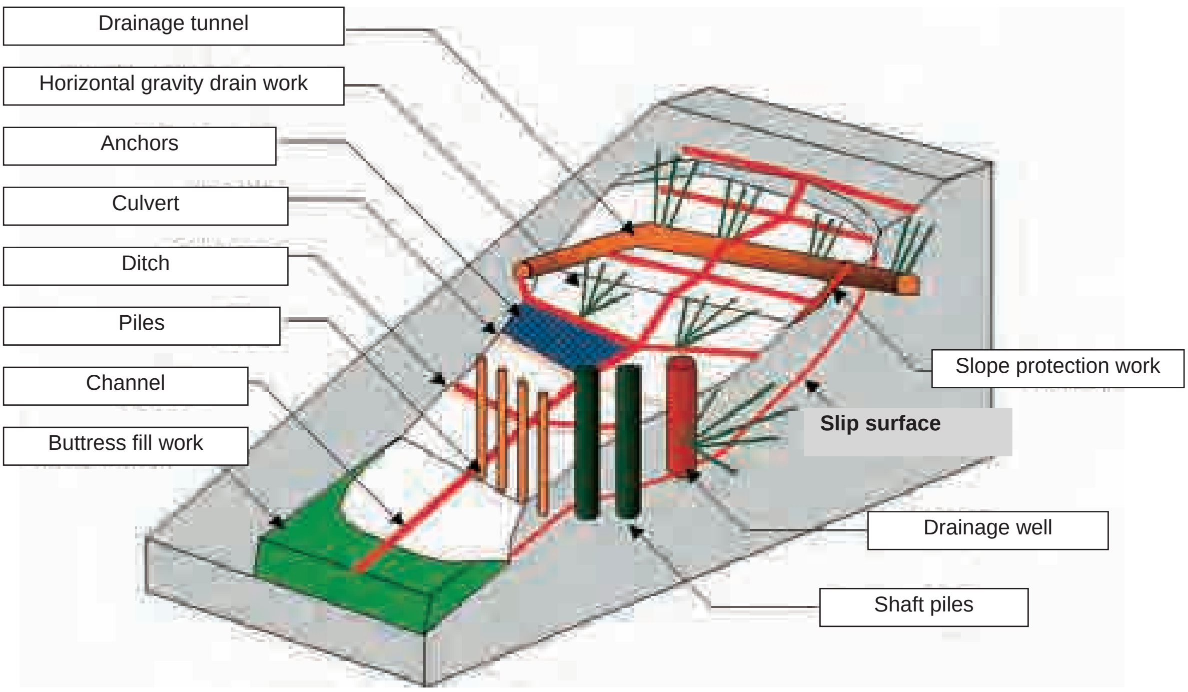


Figure 5.1.2 Schematic figure of landslide countermeasures

Surface drainage work prevents initiation of a landslide by re-infiltration of rainfall and surface water from inside and outside of the landslide areas. Shallow groundwater control work reduces the groundwater supply near the slip surface by draining it away from shallow depth. Deep groundwater control work on the other hand reduces pore water pressure near slip surfaces by draining away groundwater circulation in deeper areas. Earth removal work is generally planed in the upper zone of the landslide in order to reduce driving force. Buttress fill work is generally implemented in the toe zone of the landslide in order to increase resistance to sliding. Erosion prevention work seeks to prevent erosion and collapse from triggering a landslide.

Piles increases resistance directly by increasing the shear and bending resistance by inserting piles into the stable bedrock. Shaft piles, mainly large diameter cast-in-place shafts for deep foundation, are vertical shaft drilled into the stable bedrock and filled with reinforced concrete. Anchors increase resistance to sliding using the additional strength of the steel and the adhesion of anchors installed in the stable bedrock.

5.2 Landslide countermeasures in Abay Gorge

5.2.1 Interpretation of stability analysis

The safety factor selected for the study is 0.98 since the landslide damaged the road even when the land did not move so much. Although the variation of the groundwater level is currently unclear, landslide displacement increases when groundwater rises in the rainy season. Therefore *c'* (cohesion) is selected to be very close to zero. Table 4.6.1 presents *φ*' (internal friction angle) obtained by back analysis. Even though *c*' is assumed to be very close to zero, it is slightly different from zero, and it is considered that *c'* has a certain value due to asymmetric characteristics of the three-dimensional configuration of the landslide.

When the slip surface configurations and water level data are obtained based on additional drilling survey by GSE, *c*' and *φ*' will be determined by optimizing *φ*' to maintain consistency with each slip surface. Multiple slip surfaces, however, may be predicted in the study area. Therefore additional investigation with several strain gauges which can measure each movement of the multiple slip surfaces at the study area is planning in the near future. The additional investigation will help us to understand the accurate *c*' and *φ*' at the multiple slip surfaces.

5.2.2 Expected countermeasures in each landslide block

In all investigated landslide areas, instabilities are triggered by rising groundwater in the rainy season. The extensometer shows large movement in the rainy season. However, the landslide displacement continues to increase at some sites. In particular, several spring water and ponds are found in L/S05 and L/S28.

First, for controlling landslide movements, it is important that the ground water level is controlled by constructing ground water drainage system. For example, horizontal drainage borings are relatively cheap. Whether the landslide can be stabilized by controlling the water level with the constructed ground water drainage system should be examined.

In case the safety factor for landslides is inadequate for proposed goal, control works of drainage wells or restraint works of piles should be constructed. Otherwise, early warning/evacuation systems based on a slope monitoring system are necessary.

Table 5.2.1 lists expected landslide countermeasures in the Abay Gorge area. Table 5.2.1 is separated into two stages. The first stage includes relatively cheap landslide control works including horizontal drainage borings and buttress fill work. In the second stage, drainage wells in order to further reduce the ground water level should be installed; otherwise piles should be constructed to ensure a proper safety factor.

Before installing landslide control works and restraint works and establishing a slope monitoring system, availability of the construction technology and the economic viability within the country's realm should be examined first.

Expected countermeasures in the targeted areas are schematized in Figure 5.2.1 to Figure 5.2.5. However, when designing the countermeasure for the landslide, micro topography and surface/ground water flow at the site should be carefully reconsidered because the figures are merely schematic illustrations in the report.

Table 5.2.1 Design of countermeasures

area	plan #	Stage 1		Stage 2	
		countermeasures	**remarks**	**countermeasures**	**remarks**
L/S00	(1)	Horizontal drainage borings (embankment and upper part of the road)	Examination of effects horizontal drainage borings by monitoring of movement and water level.	Improvement of safety factor in the landslide by piles or drainage wells (depression zone and toe zone)	a) Examination of construction technology, cost. b) Monitoring of movement and water level for drainage wells
	(2)	Buttress fill works (depression zone)	Examination about the influence for lower blocks in advance	Buttress fill works (light embankment + anchors)	a) Examination of construction technology, cost.
L/S05	(1)	Horizontal drainage borings+surface drainage works (flat land in upper zone of the slope, block 05-02, 05-03, 05-04)+retaining wooden structures (block 05-02, 05-03)	a) Examination of effects horizontal drainage borings by monitoring of movement and water level. b) Retaining structures in block 05-02, 05-03 for unstable sediment	Piles or drainage wells (depression zone and toe zone)	a) Examination of construction technology, cost. b) Monitoring of movement and water level for drainage wells
L/S22	(1)	Surface drainage works		Improvement of safety factor in the landslide by piles	Examination of construction technology, cost.
	(2)	Road repair work for shelving	Examination of construction feasibility	Protect of road shoulder by H-shape steel sheet pile	Examination of construction technology, cost.
L/S27	(1)	Horizontal drainage borings (upper part and lower part of the road)		Piles (upper block of the road) or drainage wells (depression zone)	Examination of construction technology, cost. Consideration of water supply for residents
L/S28	(1)	Horizontal drainage borings (upper part and lower part of the road)+channels	a) Examination of effects horizontal drainage borings by monitoring of movement and water level. b) Bigger channels	Improvement of safety factor in the landslide by piles (depression zone) or drainage wells (middle slope)	a) Examination of construction technology, cost. b) Monitoring of movement and water level for drainage wells

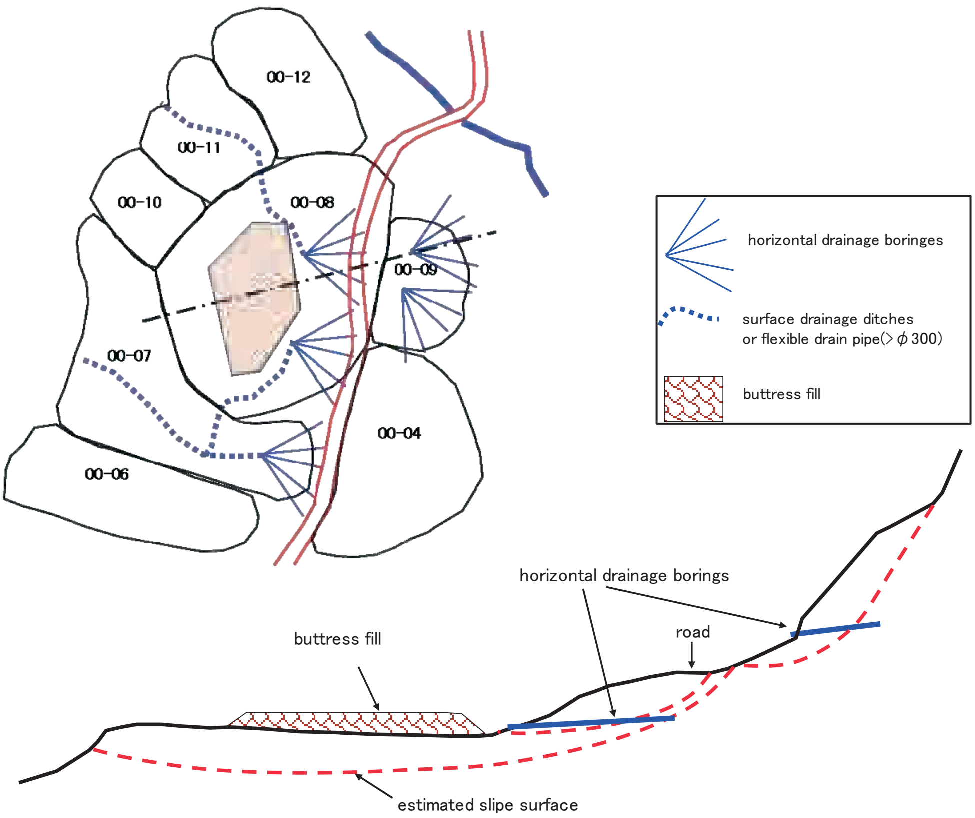


Figure 5.2.1 Schematic figures of expected countermeasure for landslide on L/S00

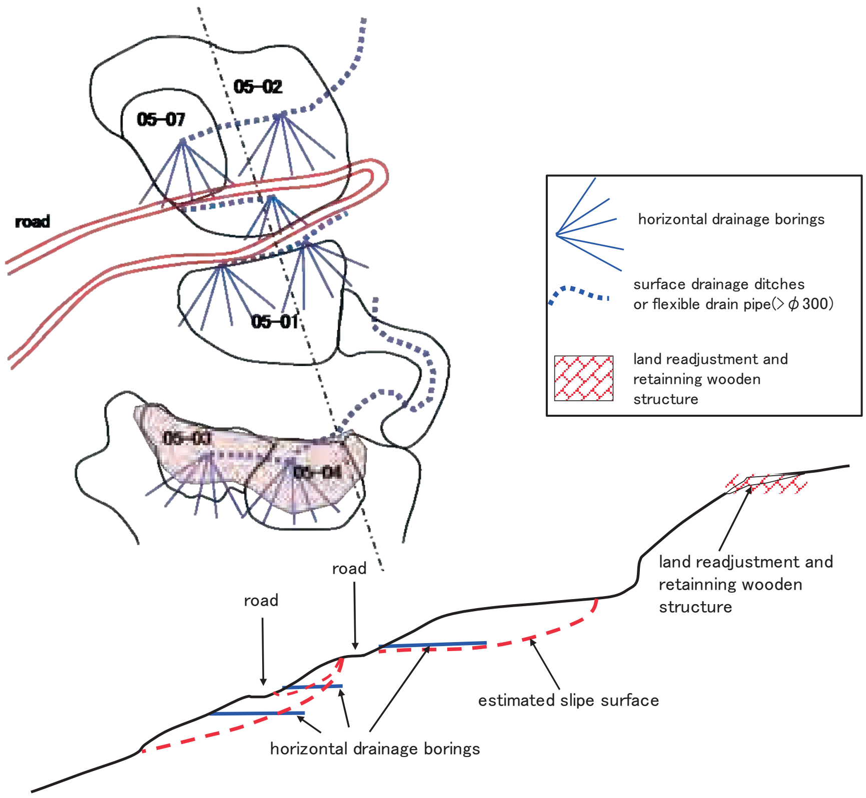


Figure 5.2.2 Schematic figures of expected countermeasure for landslide on L/S05

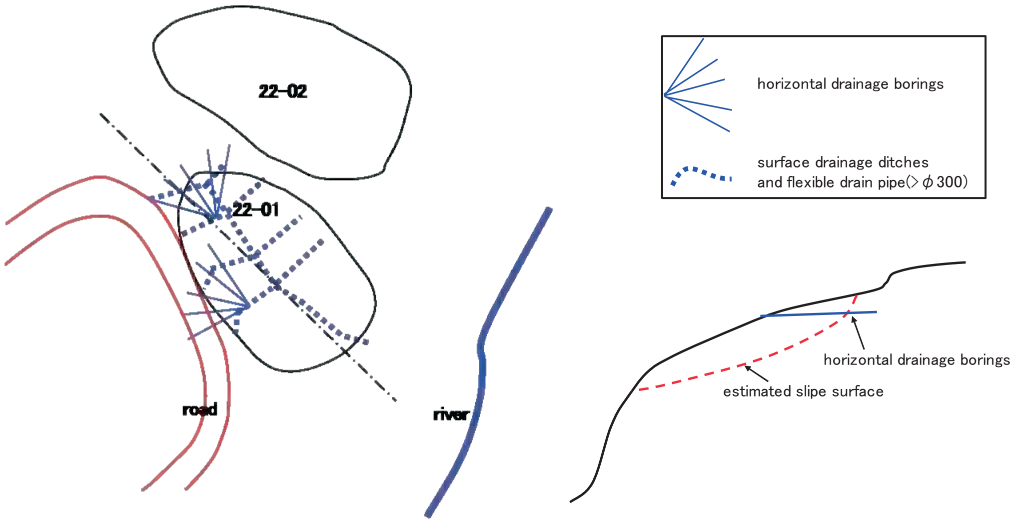


Figure 5.2.3 Schematic figures of expected countermeasure for landslide on L/S22

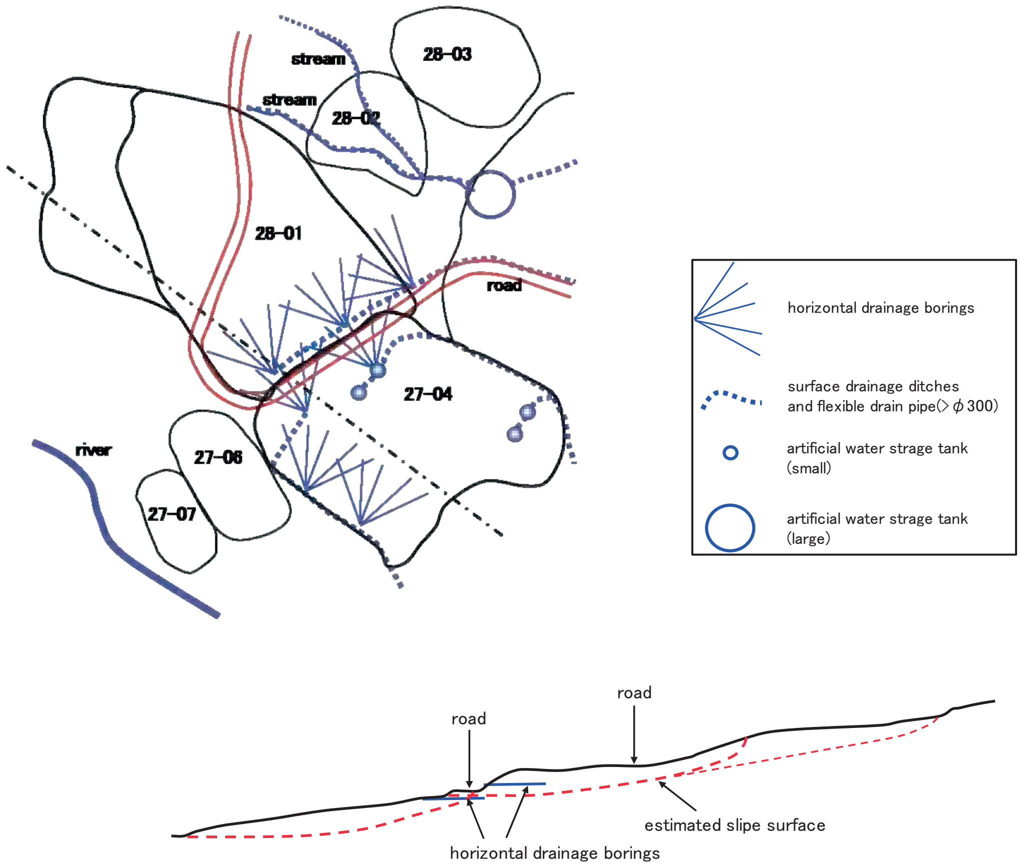


Figure 5.2.4 Schematic figures of expected countermeasure for landslide on L/S27

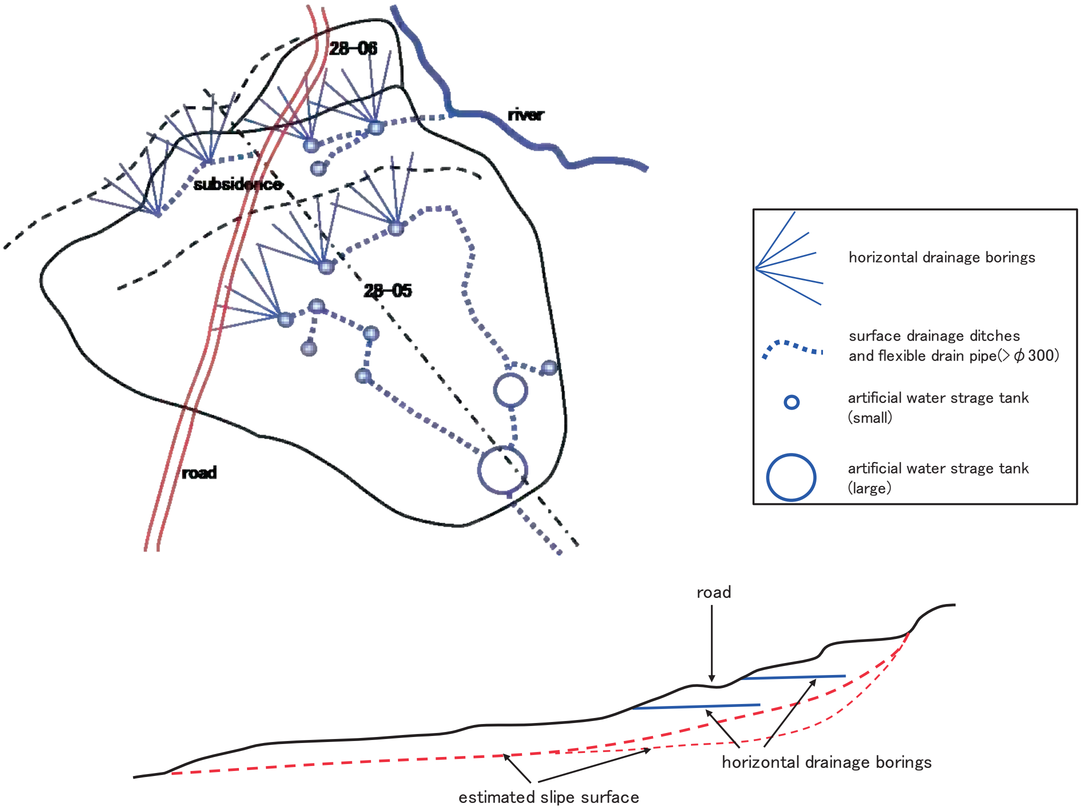


Figure 5.2.5 Schematic figures of expected countermeasure for landslide on L/S28

5.2.3 Remarks in practice

Landslides can be triggered in the rainy season by rising ground water levels. Therefore, it is rational that groundwater control work such as horizontal drainage borings would be constructed to reduce the landslide activity. However horizontal drainage borings might not be effective in some cases. Therefore the effect of the groundwater control work should be examined by monitoring movement and water level. Buttress fill work is also relatively cheap but could trigger another landslide block depending on the construction site. The influence of buttress fill work for other blocks should also be examined in advance.

Many types of erosion of the ground surface and collapses are confirmed due to rain intensity. Surface drainage work on the slope is effective to prevent rainfall water from infiltrating into moving mass of landslide and controlling rising water levels. Additionally, although drainage well effectively reduces the ground water level, residents may consume the ground water for domestic use.

5.2.4 Requirements for setting appropriate countermeasure

The discussion for setting appropriate countermeasures is divided into four parts; Investigation and monitoring, examination of practical effects of countermeasures, establishment of objective safety factors and feasibility of construction technology and economic efficiency for applying the countermeasure.

a. Investigation and monitoring

A drilling survey of the necessary volume is planed for deciding the configuration of the slip surface after selecting an appropriate site where the landslide block will need landslide countermeasures. Three to four drilling surveys will be necessary in one landslide block. At least one borehole should be deep deeply enough to cross the unstable bedrock.

The drilling survey should be done while recording the water level a day before and after completing drilling. Borehole inclinometer and water level meter should be installed in the boreholes for monitoring purpose. Water level monitoring is especially important for obtaining a reliable *φ’* in stability analysis.

The rain duration is short in the Abay area, so the sampling time should not exceed about 10 minutes. If it is difficult to install a borehole inclinometer due to cost, it is possible to replace it with borehole extensometer.

b. Examination of practical effects of countermeasures

If groundwater control work such as horizontal drainage borings and drainage wells are to be conducted, the effect of the groundwater control work should be examined by monitoring the ground movement and water level. The accuracy of the safety factor could be improved by reviewing soil constants *c’* and *φ’* in the stability analysis. Selecting an appropriate *φ’* makes a big difference for the effectiveness of the groundwater control work.

c. Establishment of objective safety factors

Even in Japan, it is difficult to establish an objective safety factor for landslides. For landslide countermeasures, it has been progressing from just setting existing safety factor and the construction works to comprehensive countermeasures including both landslide preventing works like constructions and management works after occurrence of landslides such as making hazard maps.

Considering Ethiopia's economic situation, this program involves feasibility in construction technology and economic efficiency. In the near future, the landslide administration in Ethiopia should develop a policy for achieving a certain safety factor at any level and start practicing hard countermeasure works. Nevertheless, a certain level of safety factor should be established to prevent landslides for specified levels of rainfall because landslides usually occur in the rainy season every year. The Project is hence important for establishing the guidelines. If a certain level of safety factor has not been set against landslides, precautionary evacuation measures including installation of a slope monitoring system should be in place.

d. Feasibility of construction technology and economic efficiency

It is necessary to investigate the feasibility of construction technology, the construction period, the economic efficiency, and the environment and social consideration in Ethiopia. Generally speaking, are more preferable rather than low feasibility countermeasures.

Those countermeasures which are relatively cheap and cost effective are proposed in the first stage of Table 5.2.1. However, it is necessary to re-examine the effectiveness and determine the safety factor that should be establish at certain level. In case a safety factor is proposed at the 1.05 to 1.10 level, countermeasure plans in the second stage in Table 5.2.1 are required. Because the safety factor changes with the landslide size and elements at risk, the study team must pay attention to these points as well.

5.3 Early warning and evacuation

5.3.1 General relationship between rainfall, groundwater level and landslide deformation

Figure 5.3.1 shows the relationship between rainfall, groundwater level and landslide deformation. Rainfall can result in the rising of groundwater level. At that time, the pore water pressure acting on the slip surface will increase, and a landslide deformation will be initiated.

In Abay River Gorge, monitoring on the landslide deformation is conducted with instruments, and the monitoring data are being accumulated. The monitoring data are very important for early warning and evacuation. Based on the monitoring data, a comprehensive judgment for early warning and evacuation can be carried out.

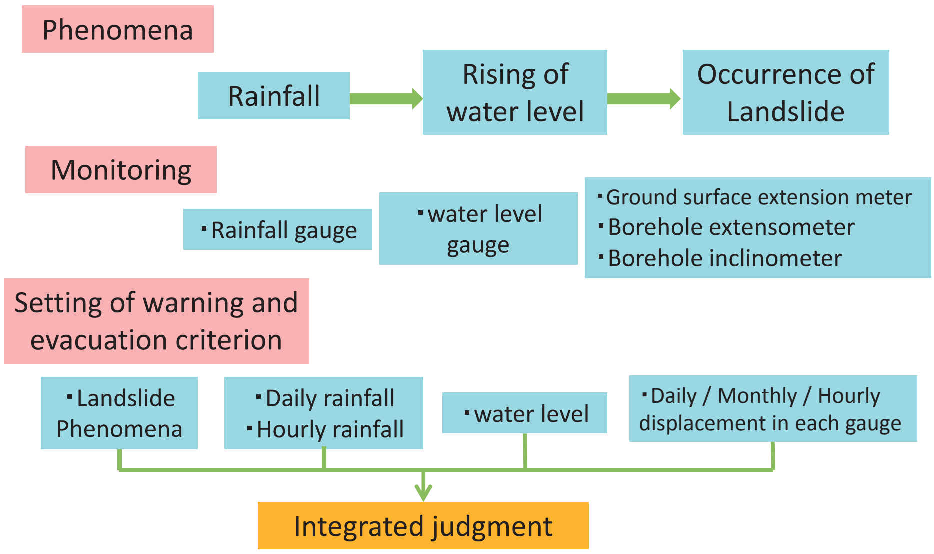


Figure 5.3.1 The relationship between rainfall, groundwater level and landslide deformation

5.3.2 Response of landslide deformation to groundwater level variation

At first, the example is presented to show the clear response of landslide deformation to the pore water pressure which is monitored in landslides in Japan.

In Figure 5.3.2, the pore water pressure is called critical pore water pressure when the landslide starts to deform (point P). From that point, the displacement monitored by slope surface extensometers starts to indicate some deformation. At the first phase when the pore water pressure just exceeds the critical pore water pressure, the landslide deformation starts to appear, but the deformation velocity is limited (Phase I in the figure). When the pore water pressure becomes larger than a critical value (point Q), the deformation velocity increases rapidly (phase II in the figure). When the pore water pressure reaches the peak value at point R, the deformation velocity reaches the maximum (point S). It should be noted that the peak point for pore water pressure (point R) is not necessary at the same peak point for deformation velocity (point S), and the peak of deformation velocity (point S) is always a little bit later than the peak of pore water pressure (point R) (called time lag phenomenon).

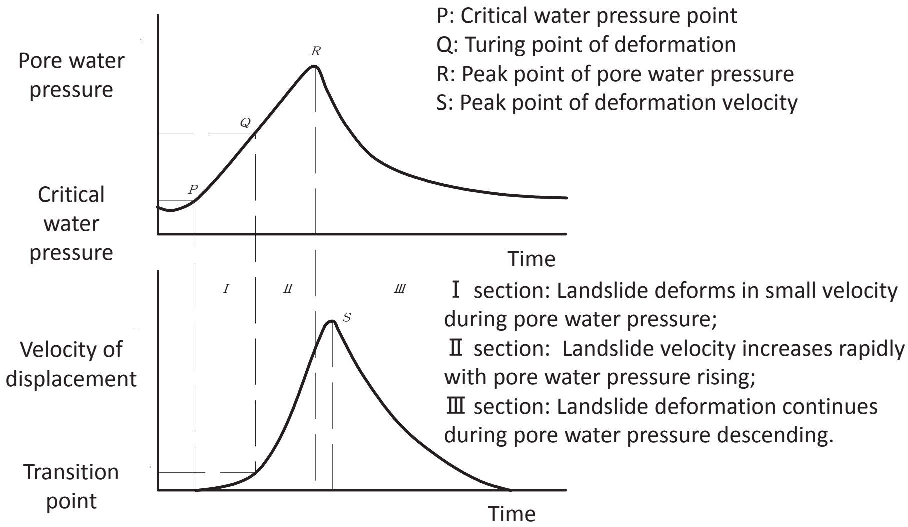


Figure 5.3.2 Time series change of pore water pressure and landslide deformation velocity

Figure 5.3.3 shows the response of landslide deformation to the pore water pressure in different types of landslide.

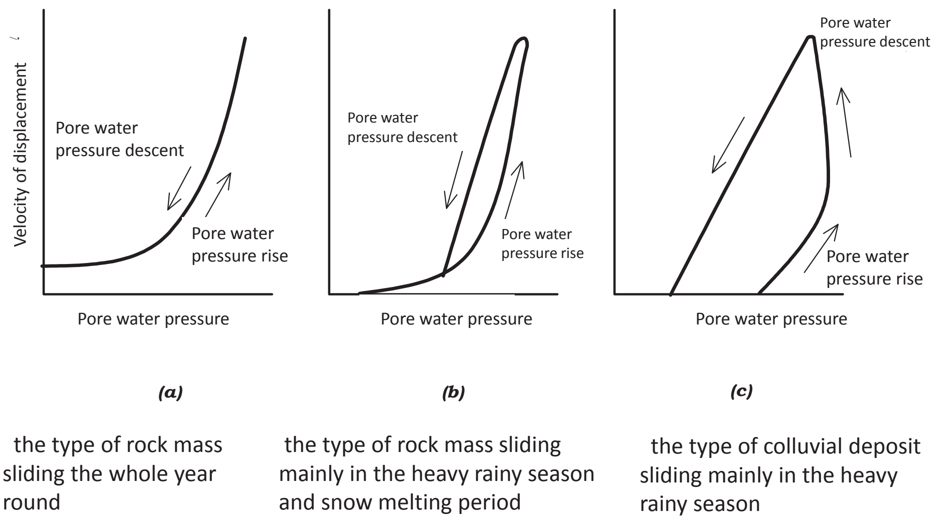


Figure 5.3.3 Relationship between deformation velocity and pore water pressure

The figure shows that type-a landslide is a year-round active rockslide. In this type, the landslide deformation sensitively responds to the variation of pore water pressure, regardless of the inducing factor, snowmelt or intense rainfall.

Type-b landslide shows a hysteresis between increasing and decreasing periods of pore water pressure. Type-b is often found in cases in which rate of increase in deformation velocity exceeds rate of increase in pore water pressure when pore water pressure increases, and rate of decrease in pore water pressure is almost the same as rate of decrease in deformation velocity when the pressure decreases. Landslides in this type are such kind of rockslide that their deformation becomes active in the intense rainfall period and snowmelt period, and attenuates to silent in dry period.

While type-c landslide shows a quite different behavior. The deformation velocity in the period of pore water pressure descending is higher than that in the period of pore water pressure rising. Such case is often found when the peak of deformation velocity comes later than the peak of pore water pressure. Actually, the difference of pore water pressure between the deformation initiating period and deformation stopping period generally occurs in colluvial deposit landslides which consist of muddy schist but the strata formed in Neogene period.

In type-b and type-c, the hysteresis exists between the two periods of pore water pressure rising and descending. In Abay River Gorge area, there are many landslides belonging to the type-b and type-c.

5.3.3 Case study of hydrological analysis in Abay River Gorge landslide areas

a. Analysis targets

The targets for hydrological analysis are L/S27 and L/S28 areas. In the analysis, the monitoring data of extensometer EX-5 are used for landslide deformation analysis, and monitoring data in B28-23 are used for groundwater level variation analysis (Figure 5.3.4).

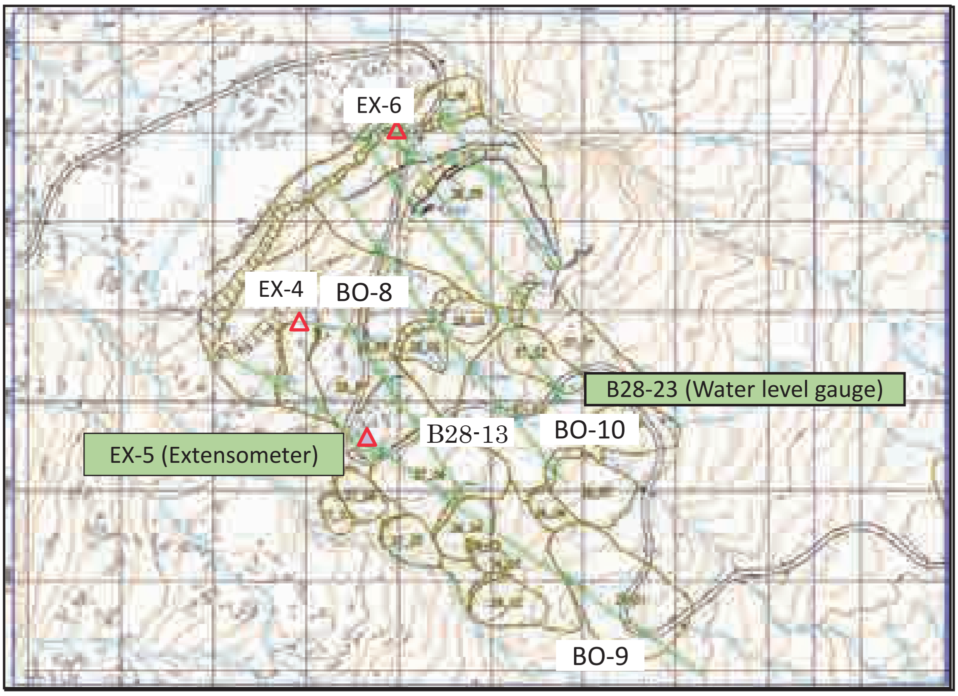
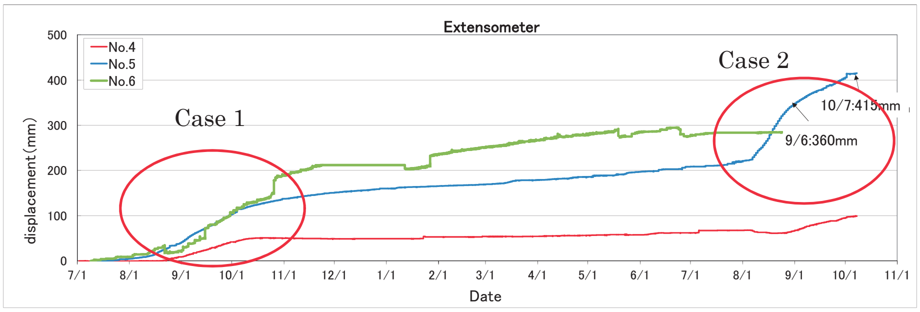


Figure 5.3.4 Target areas for hydrological analysis

b. Deformation situation of the landslide

Case 1 and case 2 indicated in Figure 5.3.5 show rapid increase in the extensometer whereas case 3 shows rapid increase in the groundwater level. Hydrological analyses are conducted for the three cases.



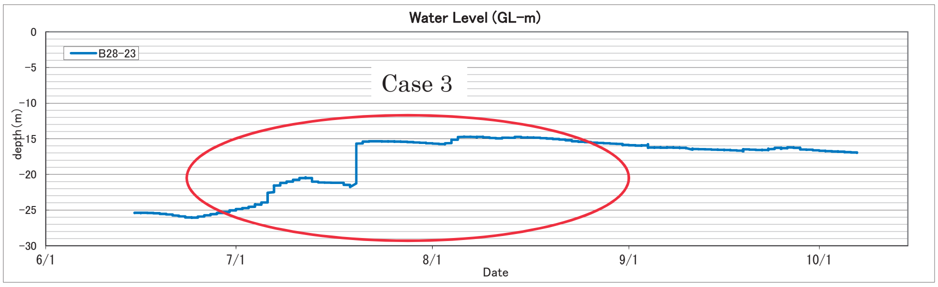


Figure 5.3.5 The landslide deformation and groundwater level in the analysis target areas

c. Rainfall data

The rainfall data used for the analysis are obtained from the nearby meteorological observation stations.

Daily rainfall for a location without meteorological observation station is calculated by weighted average method shown in Equation (1), in which using inverse distance as the weight. For the location near Gabrielle Church, three meteorological observation stations are employed, i.e., Goha Tsiyon observation point or Filiklik observation point, Abay Gorge observation point, and Dejen observation point.

$R_c = (R_1/d_1+R_2/d_2+R_3/d_3)/(1/d_1+1/d_2+1/d_3)$ • • • • • • • • • • • • Eq.(1)
R_c : daily rainfall expected in nearby location;
R_i : daily rainfall monitored at a meteorological observation station.

The distances from different meteorological observation stations to the Gabrielle Church are as follows.

Goha Tsiyon (d_1 = 14.9km), Filiklik (d_1 = 13.4km), Abay Gorge (d_2 = 5.2km), Dejen (d_3 = 6.6km)

Then using Equation (2), the practical effective rainfall affecting the landslide deformation can be obtained. The practical effective rainfall is an accumulation of the rainfall from several days before the current day considering the attenuation effect of the rainfall. The attenuation effect is represented by the attenuation factor α.

$R_{ce} = R_{c0}+\Sigma\alpha_i R_{ci}$ • Eq.(2)
R_{ce} : Practical effective rainfall;
R_{c0} : Rainfall at the current day;
α_i : Attenuation factor at previous i days
R_{ci} : Rainfall at previous i day.

Generally, the attenuation factor α should be obtained through trial and error. Here for simplicity, it can be set as, $\alpha_1 = 0.5$, $\alpha_2 = 0.25$, $\alpha_3 = 0.0625$.

d. The relationship between rainfall, groundwater level and landslide deformation

d.1 Case 1

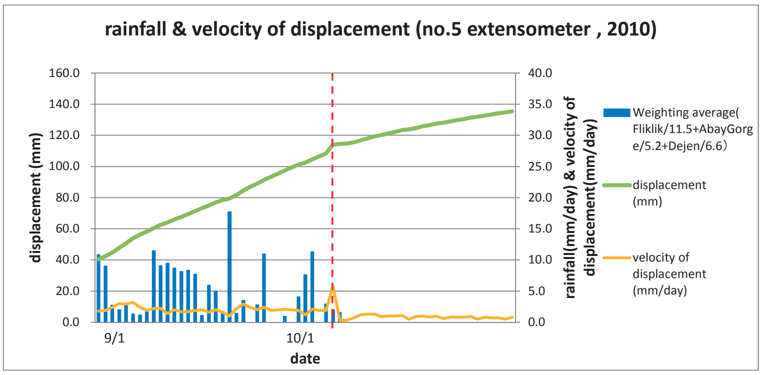
Figure 5.3.6 shows the relationship between rainfall and landslide displacement in 2010. The velocity of the displacement is also shown in this figure. The orange colored curve shows the deformation velocity of the landslide.

In Figure 5.3.6 (a), the rainfall in the current day only is used, and it does not show any relationship between the rainfall and landslide displacement.

After a trial and error process, a good relationship between the rainfall and landslide displacement was obtained when the continuous rainfall in previous four days are used to calculate the average rainfall intensity, and the time lag is three days.

Case 1

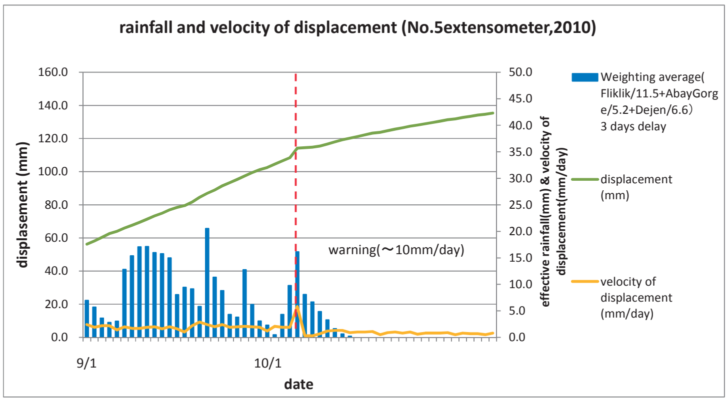
From September to October in 2010
Condition : vs. current day only



(a) Rainfall data of the current day

Case 1

From September to October in 2010
Modify condition : vs. 4 days rainfall , 3 days delay



(b) Four-day consecutive rainfall and three-day time lag prior to landslide occurrence

Figure 5.3.6 The relationship between rainfall and displacement velocity in 2010

d.2 Case 2

Figure 5.3.7 shows the relationship between rainfall and landslide displacement in 2011. After a trial and error process, it was found that the correlation was most significant in cases when the continuous rainfall in previous four days was used to calculate the average rainfall intensity and the time lag was three days.

Of course the practical effective rainfall is affected by the rainfall style. Nonetheless, it is also clear that the landslide event is affected by the rainfall of the previous days, and a time lag exists between the peak of rainfall and peak of displacement velocity.

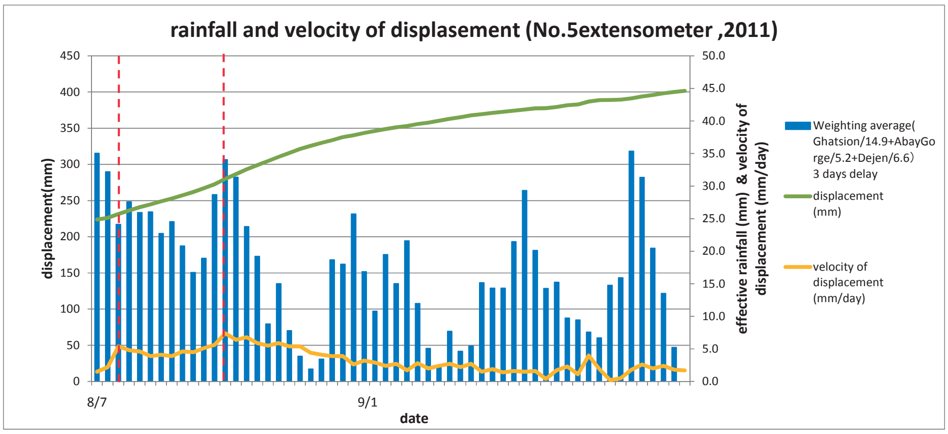


Figure 5.3.7 The relationship between rainfall and landslide displacement in 2011

d.3 Case 3

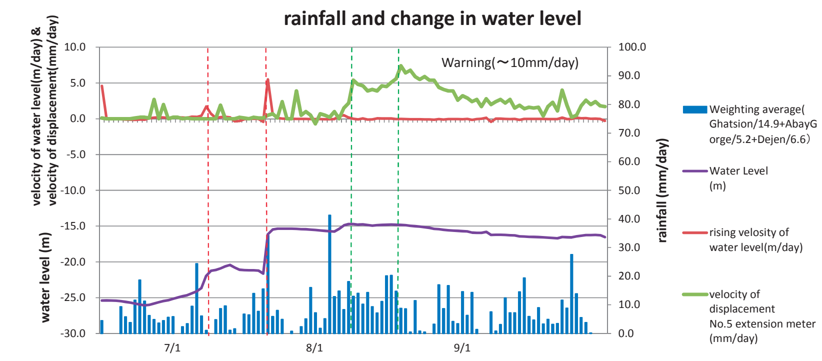
Figure 5.3.8 shows the relationship between rainfalls, groundwater level and landslide displacement in 2011. The brown curve shows the variation velocity of groundwater level, and the green curve shows the displacement velocity of the landslide.

As shown in Figure 5.3.8 (a), when only the current day rainfall data is used, it cannot be found that any relationship exists between the rainfall and groundwater level rising.

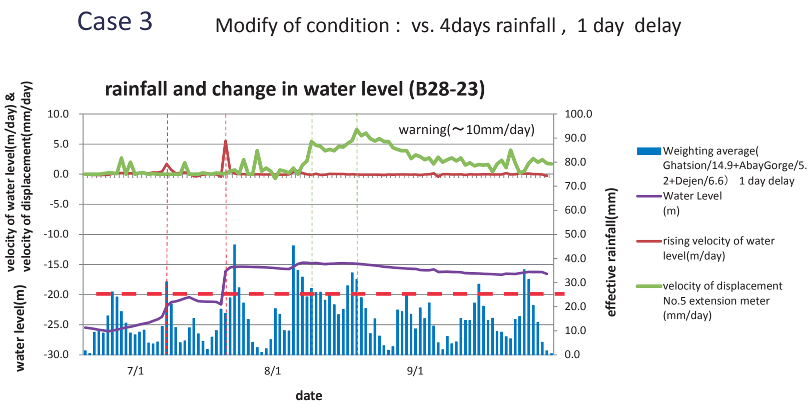
After treatment based on trial and error, the results in Figure 5.3.8 (b) were obtained, which shows a nice correlation between the rainfall and groundwater level rising, when previous four-day rainfall data is used, and the time lag is one day.

At that time, the critical practical effective rainfall to cause groundwater level rising is about 24 mm, as shown in the dotted red horizontal lines.

Case 3 Condition : vs. current day only



(a) The current day rainfall data is accounted for



(b) Four-day consecutive rainfall and one-day time lag prior to landslide occurrence

Figure 5.3.8 Relationship between rainfall, groundwater level and landslide deformation

e. Summary

The following are the summaries for the relationship between rainfall, groundwater level and landslide deformation.

- A continuous rainfall for at least four days is necessary to cause the groundwater level rising and landslide deformation. The critical practical effective rainfall is 24 mm for this landslide.
- The time lag for water level rising after the practical effective rainfall is one day, and the time lag between water level rising and landslide deformation is two days. A schematic model is shown in Figure 5.3.9.

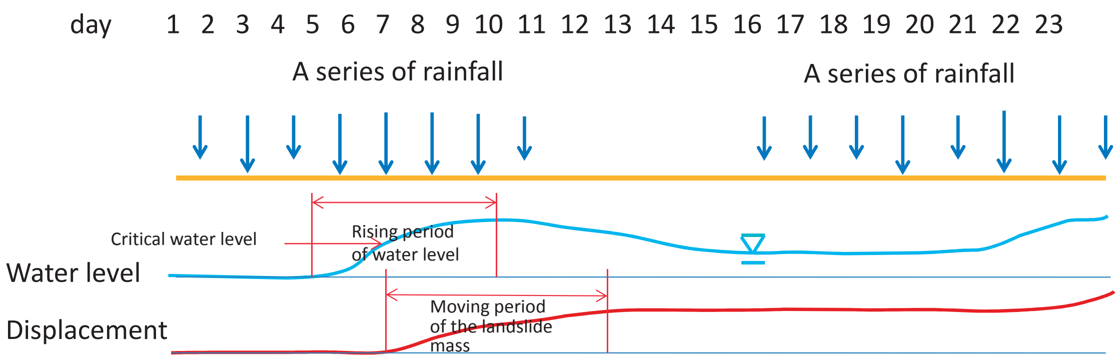


Figure 5.3.9 Schematic model between rainfall, groundwater level and landslide deformation

5.3.4 An example to set the criterion for early warning and evacuation

An example of setting the criterion for early warning and evacuation is shown in Table 5.3.1. The situation is divided into three levels. Level I means precaution, Level II means warning, and Level III means evacuation. The parameters used to determine the warning and evacuation includes two parts. One is based on the direct observation on the landslide deformation, and the other is based on the monitoring data. Data gathering, patrolling, sharing information with the local residents, and evacuation guiding are also important when monitoring landslide deformation. Furthermore, for the landslide deformation monitoring, the data of slope surface extensometer, underground deformation meter, and borehole inclinometer are generally used. Generally, the slope surface deformation is larger than that occurs in the ground, therefore the criterion value for warning and evacuation should be set larger for slope surface extensometer, and gradually smaller for ground deformation meter, and finally smallest for borehole inclinometer. Moreover, groundwater level is often used for decision making process at precaution and warning levels, but because there are lots of uncertainties in the groundwater level variation, it is rarely used to decide whether or not evacuation is necessary.

Through the hydrological analysis, overall relationship between rainfalls, groundwater level and landslide deformation was revealed. Continuous effort in accumulating monitoring data will bring further understanding of the entire phenomena.

Table 5.3.1 An example to set criterion for landslide warning, alerting and evacuation

	Rainfall	Pore water level	Extensometer	Bohehole extensometer	Bohehole inclinometer	Behavior for early warning and evacuation
Level I (precaution)	>20mm/day	–	3mm/day-1mm/day	1mm/day -0.3mm/day	0.5mm/day-0.1mm/day	Patrol
Level II (warning)	>50mm/day	critical water level	10mm/day-3mm/day	3mm/day-1mm/day	1mm/day-0.5mm/day	Patrol
Level III (evacuation)	>100mm/day and/or >50mm/hour	–	> 5mm/h	>2mm/h	>0.5mm/h	・Patrol ・Distributing information to resident ・Preparation for evacuation ・Evacuation instructions
notes		Pore water level is difficult to use for evacuation standard because it fluctuates a lot.	The evacuation standard should be established in combination with surface extensometer, bohehole extensometer and borehole inclinometer.			[Points to check] ・Generation of cracks and bumps ・Collapse of the toe of the landslide ・Damage of structure ・Murky situation of surface water and river ・Generation and dryness of spring water

5.4 Rockfall/Debris Flow Countermeasures

5.4.1 General Countermeasures

a. Common measures against rockfall

The two types of countermeasures against rockfall are “rockfall prevention work”, which keeps rockfall from occurring (countermeasure at the source), and “rockfall protection work”, which defends the downward object to be protected before fallen rocks reach it when rockfall does occur (preservation countermeasure).

Rockfall prevention work includes root protection work, unsteady rock removal, rock-bolt work, wire-rope sling work, and grating crib work. Rockfall protection work includes rockfall protection nets, rockfall protection wall, rockfall protection fence, soil embankments, and high-energy absorbing fences.

Table 5.4.1 Examples of Rockfall Prevention works

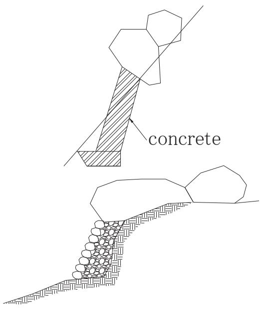
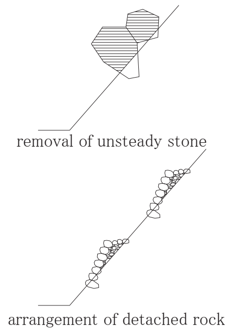
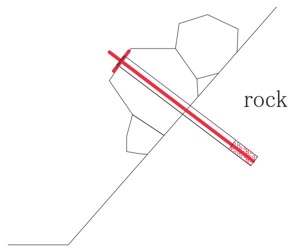
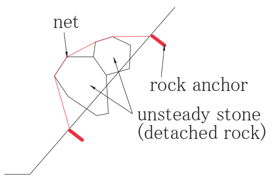
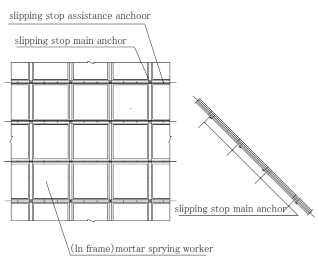
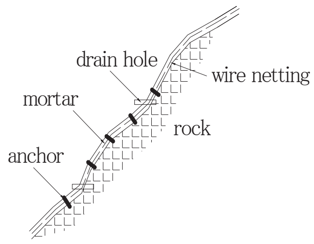
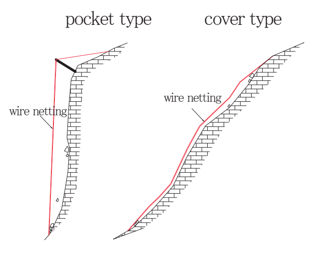
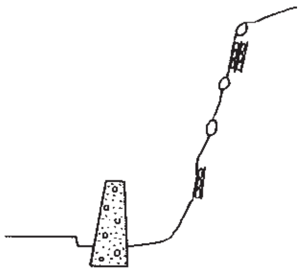
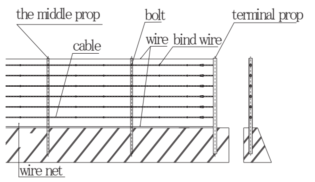
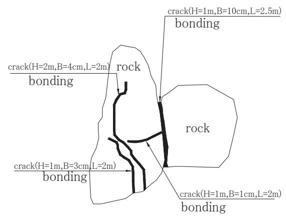
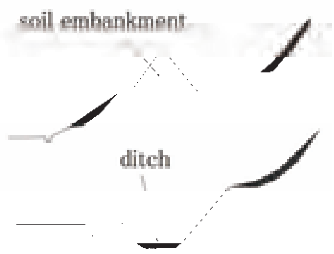
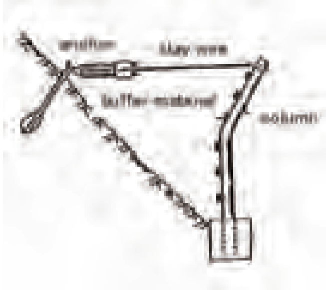
Method	Concrete root protection work	Removal of unsteady rocks/ detached rocks	Rock-bolt work
Conceptual scheme			
Feature	Use concrete to protect the base and surrounding area from unsteady rocks and/or detached rocks to stabilize them so that they do not move.	Manually gather and pile rolling rocks in safe places on the slope	Bore a hole through a large unsteady rock or detached rock, and stabilize it by inserting a bolt into the base rock
Method	Wire-rope sling work	Grating crib work	Concrete spraying
Conceptual scheme			
Feature	Weave wire ropes to form grids and fasten them with cross clips over unsteady and detached rocks so that they do not move.	Cut unstable soil and soft portions of bedrock exposed to the cliff surface, and then stabilize the slope with grating cribs	Spray concrete or mortar on the slope to prevent weathering and slipping.

Table 5.4.2 Examples of Rockfall Protection Works

<table>
<tr><td>Method</td><td>Rockfall protection net</td><td>Rockfall protection wall</td><td>Rockfall protection fence</td></tr>
<tr><td>Conceptual scheme</td><td>
</td><td></td><td>
</td></tr>
<tr><td>Feature</td><td>Cover the slope that has a risk of rockfall with wire netting and wire ropes.</td><td>Disperse or decrease the energy of rockfall by building a wall of concrete or cushion material to catch fallen rocks from the slope.</td><td>Prevent rockfall by installing a fence in the lower or middle portion of the slope where rockfall is likely to occur.</td></tr>
<tr><td>Method</td><td>Bedrock bonding</td><td>Soil embankment</td><td>High-energy absorbing fence</td></tr>
<tr><td>Conceptual scheme</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Feature</td><td>Bond desquamative bedrock and/or open joints of rock lumps at the rockfall source by glue.</td><td>Construct a soil embankment and ditch in a relatively flat landform and has an allowance to absorb and disperse the energy of fallen rocks</td><td>Install a fence with excellent energy-absorbing capacity, composed of nets and stays.</td></tr>
</table>

In some parts of the Abay area, rockfall protection walls or concrete retaining walls and gabions have already been installed.

Photo 5.4.1 Rockfall Protection Wall

Photo 5.4.2 Gabion

The effects of rockfall countermeasure include:

- Prevention of rockfall occurrence
- Absorption of falling energy
- Prevention of rockfall movement by impact resistance
- Diversion of rockfall to a harmless direction
- Prevention of weathering and erosion that cause rockfall.

b. Common countermeasures against debris flow

Suitable countermeasures against debris flow should be selected with a full understanding of the type of debris flow (stony or mud flow), amount of falling debris flow, and characteristics of the catchment basin.

The main purposes of countermeasures against debris flow are:

- Prevention of debris flow occurrence
- Stopping and depositing the debris flow during its movement
- Conversion of debris flow into sediment flow or bed-load transport
- Running though debris flow by a harmless way.

The two types of countermeasures against debris flow are hardware countermeasures, which use structures such as sabo dams, training dikes and channel work, and software countermeasures, which do not use structures such as proper land use, evacuation, and reinforcement of buildings.

Examples of hardware countermeasures are listed in Table 5.4.3.

Table 5.4.3 Types of Debris Flow Countermeasure Facilities

Type of countermeasure facility	Example of work	Main effects
Debris flow capturing work	Dams ・Non-permeable ・Permeable	Reducing the amount of debris that flows down as debris flow
Debris flow training dike	Channel work	Preventing debris flow from reaching the area to be preserved
Debris flow deposition structure	Depositing ・Sediment-retarding basins ・Desilting basin	Reducing the amount of debris that flows down as debris flow
Buffer forest zone against debris flow		
Debris flow direction controlling works	Guide bank	Preventing debris flow from reaching the area to be preserved
Works for controlling occurrence of debris	Low dams ・Non-permeable ・Bed protection works ・Channel work ・Hillside protection work	Preventing debris flow (including expansion of erosion)

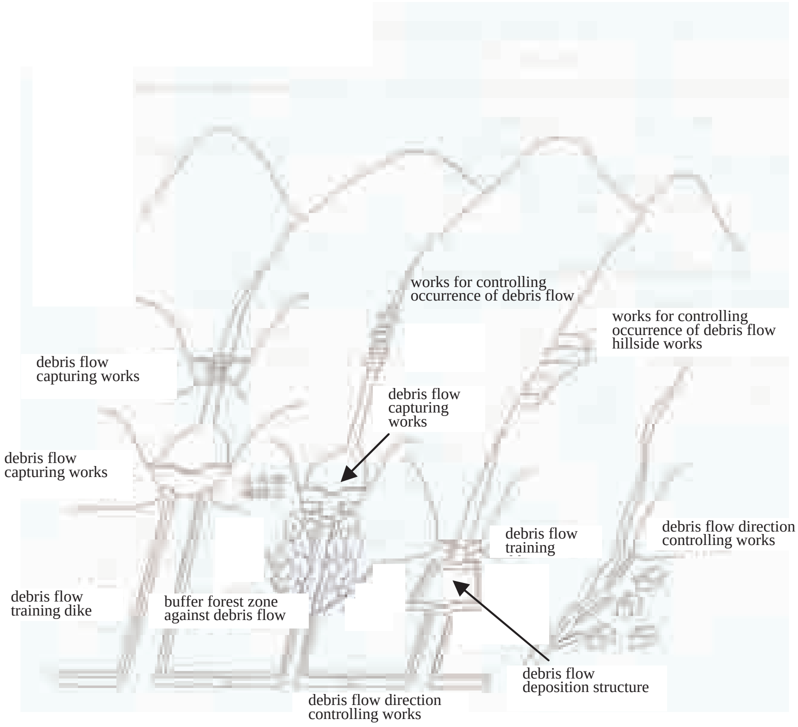


Figure 5.4.1 Representative Debris Flow Countermeasure Facilities

In the Abay area, counter facilities that have already been installed include sabo dams, channel works as well as gabions.

Photo 5.4.3 Sabo Dam

Photo 5.4.4 Channel Work

Photo 5.4.5 Gabions installed in streambed

Photo 5.4.6 Gabions along the stream banks

5.4.2 Application of countermeasure on rockfall/debris flow

a. Applicability of countermeasures against rockfall

Both fall-off-type rockfall and exfoliating-type rockfall can be observed in the Abay area. The sources include rockfalls from the natural slopes, rockfall from the cut slopes, and combinations of these.

The energy of a rockfall from the natural slope is usually great because the slope is high and there are rocks with diameters exceeding 1m. In such cases, high-energy-absorbing rockfall countermeasures are suitable. When there are few fallen rocks or the source of rockfall can be identified, however, such rockfall prevention countermeasures as root protection works and removal of unsteady and detached rocks are also appropriate.

For rockfalls from the cut slope, cracks develop or weathering advances over the slope; thus, rockfall from the whole surface of the slope can be observed. Most fallen rocks have 0.3m diameter or less with less rockfall energy. Therefore, various countermeasures may be appropriate. Many cut slopes are near roads, so construction of a grating crib work or a rockfall protection net may be considered.

Photo 5.4.7 Fall-off Type Rockfall

Photo 5.4.8 Detached-away Type Rockfall

Photo 5.4.9 Rockfall from a Natural Slope

Photo 5.4.10 Rockfall from a Cut Slope

Selection of the most suitable rockfall countermeasure or combination of countermeasures for the state of the road and the state of the slope at the site should involve consideration of functions, durability, workability, economic efficiency, and potential maintenance and management problems for countermeasures. Selection of the most suitable rockfall protection work should involve consideration of rockfall energy.

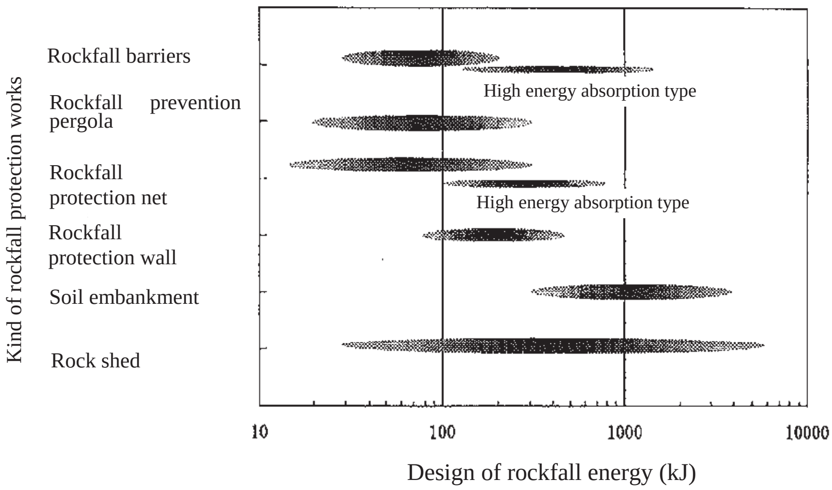


Figure 5.4.2 Guideline for Applicable Range of Rockfall Countermeasures

b. Applicability of countermeasures against debris flow

Many of the streams in the Abay area are short length, and steep slopes. The type of debris flow is stony debris flow, and the amount of sediment to flow out is estimated to be 100m^3 or less in most cases.

The danger of flow-out of a large volume of sediment is low, in light of the amount of continual rainfall, current deposit on the stream bed, and the state of hillside collapse upstream; therefore, debris flow capturing works (e.g., sabo dams) are suitable. However, construction of large dams is difficult on narrow streams that have shallow river beds. The installation of low dams as bed protection works to suppress the occurrence of debris flow is appropriate.

For streams in Filiklik Village, where debris flow disasters have occurred in the past, unstable sediment deposits are relatively thicker; thus, it is necessary to consider combination of direction controlling works, and occurrence controlling works to prevent debris flow.

In this area, there are many streams where drainage processing is insufficient or cross-drainage facilities are blocked with pebbles. For these streams, it is desirable to extend channel work or remove deposited sediment.

Photo 5.4.11 Insufficient Drainage Processing

Photo 5.4.12 Blocking of a Box Culvert

Many sabo dams are filled with sediment and their sleeves are damaged, so they are not fully functional. Moreover, some of the dams are of insufficient height or have insufficient strength. For a high risk debris flow channel where discharge of sediment is repeated, it is necessary to predict the discharge volume of sediment and to install sabo dams of appropriate sizes. Existing dams with decreased functions require repair and/or reinforcement.

Photo 5.4.13 Damaged dam sleeves

Photo 5.4.14 Crown width(approx.40cm)

Photo 5.4.15 Damaged dam sleeves

Photo 5.4.16 Spillway (approx.1.5m)

It is difficult to install sabo dams on small streams. For the small streams, debris flow training dike or debris flow deposition structure is appropriate if procuring of the land is possible.

5.4.3 Requirement for setting appropriate countermeasure

a. Requirement for setting countermeasure against rockfall

To implement appropriate rockfall countermeasures, it is important to determine and record the locations, the diameters of fallen rocks, and the conditions at the time of rockfall disasters (season and amount of rainfall). When the rockfall source and the rockfall path can be identified, it is possible to select the type of works that is suitable for the size of rockfall and to plan effective countermeasures.

Rockfall countermeasures use many concrete structures and flexible structures, and soil embankment work involves civil engineering. However, the removal of unsteady rock/detached rocks is performed manually. These rockfall countermeasures do not require any special construction machinery.

Some rockfall prevention works (e.g., grating crib work and concrete spraying) and rockfall protection works (rockfall protection walls and fences) use concrete and reinforcing steel bars as the main materials. Construction of these structures requires measuring equipment, kneading machines, spray machines, and their accessory devices. While some materials (e.g., cement and reinforcing steel bars) can be procured at the site, it is important to secure stable, high-quality supplies.

For structures that are made up mostly of reinforcing bars and metallic products (e.g., flexible structures), procurement of materials that have the prescribed strength and processing techniques are required.

When implementing each countermeasure, it is important to prepare manuals to ensure that construction technique, quality control, work progress control, and construction management standards suitable for each type of works are properly implemented.

b. Requirement for setting countermeasure against debris flow

To implement appropriate countermeasures against debris flows, it is important to understand and record the state of debris flows in the past, volume of sediment deposited in streams, the state of hillside collapses, and the season and the amount of rainfall during debris flow.

In planning the size of a sabo dam, the amount of rainfall for 100 years probability or the largest amount of rainfall in the past (whichever is greater) should be adopted. Therefore, it is important to analyze the records of rainfall amounts at each observation station. Observation data must include the amount of rainfall per hour.

The structure and size (e.g., height, thickness at the top end, and gradient of slope) of the sabo dam to be constructed should be determined by performing stability calculations considering the effect of the countermeasures, workability, and economic efficiency. Existing dams are thin at the top (50cm or less) with insufficient foundation of sleeves, and they are weak.

Designing stable sabo dams requires design standards that are suitable for the district.

Construction of sabo dams requires a large volume of specialized heavy machines (e.g., truck cranes, concrete mixer cars, mobile concrete pumps, backhoes, and rough terrain transportation vehicles). It is important to procure construction machines and a supply of stable, high-quality materials.

Furthermore, it is necessary to prepare manuals to ensure that construction methods, quality control, work progress control, and construction management standards for properly implementation.

Chapter 6

Technical Transfer

6 Technical Transfer

6.1 Methodology

6.1.1 Improvement of the capacity of C/P regarding landslides

a. Confirm GSE's capacity

- Examine the personal, organizational and social capacity of the C/P using a checklist

b. Propose gradual technical transfer

- Progress the capacity development gradually, through three phases.

Table 6.1.1 Method of capacity development in each stage of development

Development stage	Phase	Method of capacity development
- Field reconnaissance and various monitoring skills	Phase 1	The Study Team will transfer basic skills such as how to select equipment necessary for landslide surveys/analysis and sites to install it, and monitoring methods. Also, transfer perspectives on prioritizing areas of risk using aerial photographs and field surveys. Further, transfer methods of surveying and analyzing slope disasters besides landslides.
- Various data analysis skills	Phase 2	The Study Team will transfer skills to figure out contributing factors and mechanisms that trigger landslides based on the data gained in phase 1.
- Application of analysis skills	Phase 3	Transfer practical analysis skills after gaining monitoring data from the target area; while making the most of the knowledge gained in phase 2. Also, give instruction to ERA—the organization in charge of countermeasures—on methods of technical response.

c. Confirm Project Design Matrix (PDM) content

- Project Cycle Management (hereinafter PCM) will be used for project management/monitoring
- Discuss and collect information on the draft performance grid with the Ethiopian side in the first year

6.1.2 Effective technical transfer on landslide

a. Share landslide classification methods and selection of landslide sites suitable for monitoring

- Accurately ascertain landslide type: creep landslide, slope failure, debris flow
- Classify, together with the Study Team, landslides from the results of past projects, risk of occurrence, and by type
- Select landslide sites that are relatively easy to understand and set-up minimal measuring equipment.

b. Introduce methods of evaluating risk

- Establish evaluation methods appropriate to the natural and social conditions in Ethiopia, based on the methods being used in Japan
- Consider the timing of warnings and the type of preventative measures based on the amount of extensometer or inclinometer movement

6.1.3 Support investigation into effective landslide countermeasures

a. Consideration of measures appropriate to socioeconomic conditions in Ethiopia

- Consider measures appropriate to future road usage based on the landslide mechanisms
- Develop an early-warning system by identifying sections that are blocked-off or reduced to one lane because of heavy rain.

b. Joint Coordination Committee (JCC)

- Hold JCC meetings that fulfill the functions of both steering and technical committees, so that the Project is implemented smoothly.

c. Regular Meetings

- Hold regular meetings, as a rule, every other week.
- The meetings will discuss the activities and issues from the previous meeting, and activities planned until the next meeting and their issues.

d. C/P Training in Japan

- The trainees will get to experience advanced landslide survey and analysis cases in Japan, and will consider the survey system and the way that analysis is undertaken in their own country. The training in Japan is planned to be executed in phase 3.

e. Promote understanding among road users and local residents

- The C/P should explain the Project works sufficiently to road users and local residents, and try to get them to cooperate in monitoring as much as possible.
- Actively publicize the state of project implementation to local residents through mass media, seminars and wall posters.

6.2 Structure of technical transfer

For the effective and smooth technical transfer, the initial idea was to form groups based on the respective expertise of both the Study Team and C/P. The groups are basically comprised as follows in Table 6.2.1. However, the concept of the technical transfer was to transfer a basic understanding and know-how of landslide surveys and analysis to all the members of the C/P.

Table 6.2.1 The Study Team Members by Group of Expertise

	Group/Expertise	JICA Expert	Counterpart	Remarks
1	Team Leader	Kensuke ICHIKAWA	Getnet MEWA	
2	Geomorphological Analysis	Satoru TSUKAMOTO Mitsuya ENOKIDA	Leta ALEMAYEHU Melukamu TEGEGNE	
3	Hydrological Analysis	Shigekazu FUJISAWA	Demis ALAMIREW	
4	Geological Analysis Landslide Monitoring	Takeshi KUWANO Makito NODA Shoji TSUCHIYAMA	Solomon GERA Zulfa ABDURHAMAN	
5	Landslide/Rockfall/ Debris Flow Analysis	Masao YAMADA Shigekazu FUJISAWA Yoichi KASAHARA	Zulfa ABDURHAMAN Yewubnesh BEKELE	
6	GIS Database	Yoshimizu GONAI	Yewubnesh BEKELE	
7	Geophysical Survey, Analysis	Naohiro ISOGAI	Tadesse LEMA Sisay ALEMAYEHU	
8	Drilling Survey	Takashi SUZUKI	Bayu WEDAJ	
9	Topographic Survey	Shozo SHIMODA	Haile G/SELASSIE	

The schematic image of the technical transfer is shown in the Figure 6.2.1. The transfer was made from group of Experts to the C/P group so that the transfer will benefit most of the C/P regardless of the C/P's expertise.

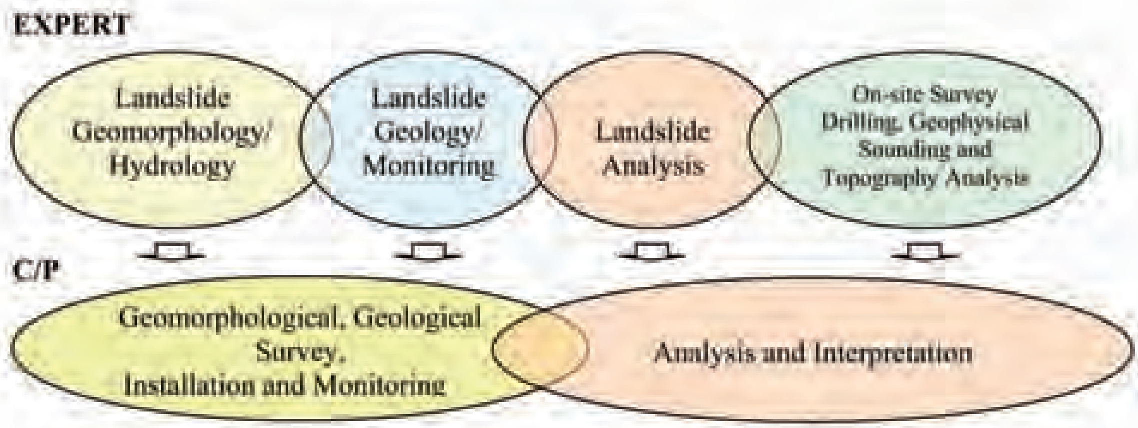


Figure 6.2.1 Structure of Technical Transfer

6.3 Main contents of technical transfer

6.3.1 Technical Transfer Seminar

a. 1st technical transfer seminar

The 1st technical transfer seminar was held on 18 November 2010 aimed to confirm the technology C/P had learned and to wrap up the activities of Phase 1. The seminar was presented by both the Expert Team and C/P Team. The major contents are shown in the seminar agenda shown in Figure6.3.1. The Seminar was initiated by Dr Getnet Mewa and followed by keynote by Mr. Masresha G/Selassie the Head of Geological Survey of Ethiopia.

b. 2nd technical transfer seminar

The 2nd technical transfer seminar was held on 8 April 2011 aimed to wrap up the activities of Phase 2. The seminar was presented by both the Expert Team and C/P Team. The major contents are shown in the seminar agenda shown in Figure 6.3.1. The Seminar was initiated by Dr Getnet Mewa and followed by keynote by Mr. Masresha G/Selassie the Head of Geological Survey of Ethiopia. They offer their deep condolence to the people in Japan who suffered by huge earthquakes and tsunami on 11th March 2011. The Expert team also expressed their thanks for their attention to the disaster in return.

c. Final technical transfer seminar

The final technical transfer seminar was held on 24 November 2011 aimed to wrap up the activities of the whole project. The seminar was presented mainly by C/P Team, supported by the Study Team. The major contents are shown in the seminar agenda shown in Figure 6.3.1. The Seminar was initiated by Dr Getnet Mewa and followed by keynote by Mr. Masresha G/Selassie.


FIRST TECHNICAL TRANSFER SEMINAR ON LANDSLIDE INVESTIGATION METHODS

SECOND TECHNICAL TRANSFER SEMINAR ON LANDSLIDE INVESTIGATION RESULTS AND ANALYSIS

FINAL TECHNICAL TRANSFER SEMINAR ON LANDSLIDE INVESTIGATION

Figure 6.3.1 Agendas of Technical Transfer Seminar

Photo 6.3.1 Technical Transfer Seminar 2

6.3.2 Work shop

Several work shops for certain themes have been conducted by the Study Team to accelerate C/P's understanding for landslide survey, analysis and evaluation in the Project as follows.

Table 6.3.1 Summary of landslide work shop

Contents	Date/Time	Place	C/P	JICA expert
GIS fundamental	10 Jun. 2010, 11:00-12:00	GSE	Yewubnesh Bekele, Tesfaye Shewa	Y. Gonai
Monitoring data organization (1)	13, 14 Oct. 2010, 10:00-12:00	GSE	Getnet Mewa, Solomon Gerra, Demis Alamrem, Leta Alemayehu, Tekalegne Tesfaye, Melkamu Tegegne, Beruku Abel , Habtamu Eshetu, Yewubnesh Eshetu Bekele	S.Tsuchiyama, Y. Yamamoto
Landslide, debris flow and rock fall survey/analysis (1)	25 Feb. 2011, 9:00-17:00	GSE	Getnet Mewa, Leta Alemayehu, Hailesalassie G/lselassie, Tekalegne Tesfaye, Sisay Alemayehu, Debebe Kifle, Melkamu Tegegne, Brook Abel, Habtamu Eshetu	S. Fujisawa, M. Yamada, M. Enokida, Y. Kasahara, Y. Gonai
GIS utilization in landslide project	18 Mar. 2011, 9:00-17:00	GSE	Getnet Mewa, Habtamu Eshetu, Ezera Tadesse, Debebe Kifle ,Yewubinesh Bekele, Brook Abel, Sisay Alemayehu, Haileslassie G/selassie, Melakamu Tegegne, Tadesse Lemma, Tekaligne Tesfaye	Y.Gonai
Landslide, debris flow and rock fall survey/analysis (2)	7 Oct. 2011, 10:00-12:00	GSE	Tekaligne Tesfaye, Beruku Abel, Yewubnesh Bekele, Debebe Kifle, Zulfa Abdurahman	Y. Kasahara, M. Noda, Y. Gonai
Monitoring analysis	11 Oct. 2011, 14:00-17:00	GSE	Demis Alamrem, Samiel Molla, Tekalegne Tesfaye, Habtam Eshete, Beruku Abel, Yewubnesh Bekele, Zulfa Abdurahman	S.Tsuchiyama, M. Enokida, Y. Gonai
Early-warning system	13 Oct. 2011, 14:00-17:00	GSE	Demis Alamrem, Samiel Molla, Tekalegne Tesfaye, Habtam Eshete	S. Tsuchiyama, Y. Gonai
Monitoring data organization (2)	14,16 Oct. 2011, 10:00-12:00	GSE	Demis Alamrem, Habtam Eshete, Samiel Molla, Beruku Abel, Tekalegne Tesfaye, Zulfa Abdurahman	S. Tsuchiyama
GIS, hydrological observation, soil parameter of stability analysis	25 Oct. 2011, 14:30-17:00	GSE	Tekaligne Tesfaye, Samuel Molla, Yewubnesh Bekele, Demis Alamirew, Habtamu Eshete, Biruk Abel, Debebe Kifle, Zulfa Abdurahman, Tewodros Alene(ERA)	S. Fujisawa, Y. Gonai, M. Enokida
Exercise of stability analysis	1 Nov. 2011, 14:30-15:00	GSE	Tekaligne Tesfaye, Samuel Molla, Yewubnesh Bekele, Demis Alamirew, Habtamu Eshete	M. Enokida
Integrated analysis	7 Nov. 2011, 4:00-16:00	GSE	Demis Alamirew, Samuel Molla, Tekalegne Tesfaye, Habtam Eshete, Sisay Alemayehu, Erza Tadesse, Yewubnesh Bekele, Debebu Tekle	M. Yamada, S. Tsukamoto, K. Ichikawa

a. GIS fundamental

Table 6.3.2 Contents of GIS fundamental seminar

Date / Time	10 Jun 2010, 11:00-12:00
Place	JICA project office in GSE
Participant	Yewubnesh Bekele, Tesfaye Shewa
Style	On-the-job training based GIS training
Contents	1. Introduction of GIS; thematic layers and datasets, georeferencing, types of geographic datasets, GIS data types, coordinates, etc. 2. Utilization of free data from the internet: Digital Chart of the World server, MapLibrary.org, ASTER-GDEM, SRTM, MrSID, LANDSAT, Earth Explorer, etc. 3. How to make base map for the field survey (data preparation)

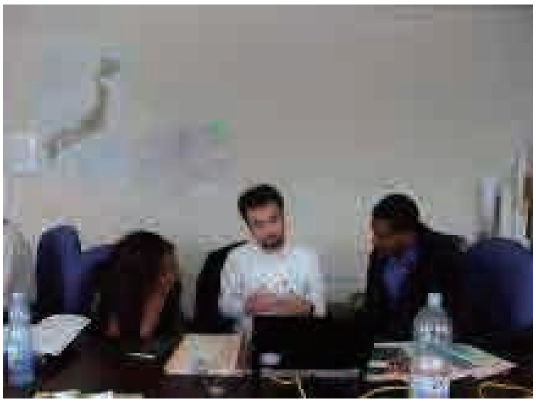
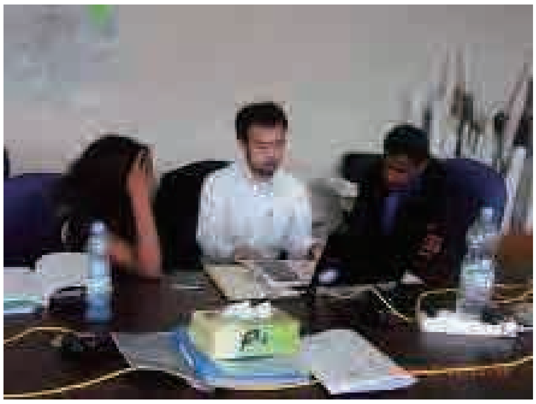



Photo 6.3.2 Photo of GIS fundamental seminar

b. Monitoring data organization (1)

Table 6.3.3 Contents of monitoring data organization seminar (1)

Date / Time	13, 14 October 2010, 10:00-12:00
Place	JICA project office in GSE
Participant	<C/P> Dt.Getnet Mewa, Solomon Gerra, Demis Alamrem, Leta Alemayehu, Tekalegne Tesfaye, Melkamu Tegegne, Beruku Abel , Habtamu Eshetu, Yewubnesh Eshetu Bekele <JICA experts> Shoji Tsuchiyama, Yosuke Yamamoto
Contents/ schedule	1)Warning standard based on monitoring device 2) General early-warning system 3) Early-warning system in Abay Gorge

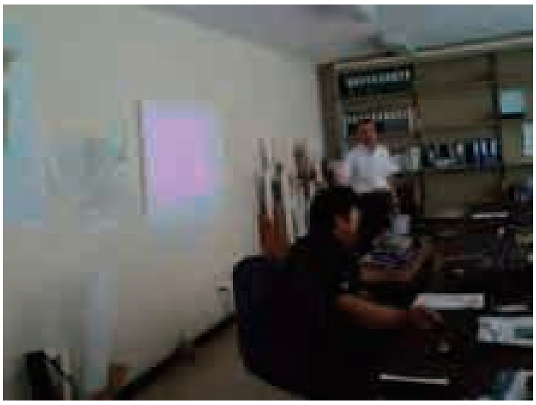



Photo 6.3.3 Photo of monitoring data organization seminar (1)

c. Landslide, debris flow and rock fall survey/analysis

Table 6.3.4 Contents of landslide, debris flow and rock fall survey/analysis seminar (1)

Date / Time	25 February 2011, 9:00-17:00
Place	JICA project office in GSE
Participant	<C/P> Getnet Mewa, Leta Alemayehu, Hailesalassie G/lselassie, Tekalegne Tesfaye, Sisay Alemayehu, Debebe Kifle, Melkamu Tegegne, Brook Abel, Habtamu Eshetu <JICA experts> Shigekazu Fujisawa, Masao Yamada, Mitsuya Enokida, Youichi Kasahara, Yoshimizu Gonai
Contents/schedule	09:10-09:40 Methods of Landslide Stability Analysis 09:50-10:30 Interim Result of Stability Analysis 10:40-11:20 Debris flow and Rock fall Analysis 11:20-11:30 Break 11:30-12:00 Free Discussion 12:00-14:00 Lunch 14:00-17:00 Practice (1) Drawing of landslide cross sections (2) Basics of stability analysis software (GEO 5) (3) Process of debris flow and rock fall analysis
Items of the free discussion	・ Potential lines of the landslide section ・ Parameter setting (c’,φ’) for stability analysis ・ Investigation method of countermeasure constructions ・ It is necessary to observe/measure the effects of horizontal drilling. ・ The meaning of removable bed in debris flow analysis software ・ Usefulness for prevention of debris flow in case of setting the dam on upstream ・ Design method of dams based on results of the analysis (c.f. height, thickness of the structures) ・ Improvement/upgrade of skill and knowledge of GSE staffs is required for advice to ERA.

Photo 6.3.4 Photo of landslide, debris flow and rock fall survey/analysis seminar (1)

d. GIS utilization in landslide project

Table 6.3.5 Contents of GIS utilization in landslide project seminar

Date / Time	18 March 2011, 9:00-17:00
Place	C/P office in GSE
Participant	<C/P> Getnet Mewa, Habtamu Eshetu, Ezera Tadesse, Debebe Kifle ,Yewubinesh Bekele, Brook Abel, Sisay Alemayehu, Haileslassie G/selassie, Melakamu Tegegne, Tadesse Lemma, Tekaligne Tesfaye <JICA experts> Yoshimizu Gonai
Contents	1. Brief meeting about the OJT & setting of computers 2. Case study 1: making base map 3. Case study 2: making field survey map 4. Case study 3: basic analysis for Landslide


Photo 6.3.5 Photo of GIS utilization in landslide project seminar

e. Landslide, debris flow and rock fall survey/analysis (2)

Table 6.3.6 Contents of landslide, debris flow and rock fall survey/analysis seminar (2)

Date / Time	7 October 2011, 10:00-10:00
Place	JICA project office in GSE
Participant	<C/P> Tekaligne Tesfaye, Beruku Abel, Yewubnesh Bekele, Debebe Kifle, Zulfa Abdurahman <JICA experts> Yoji Kasahara, Makito Noda, Yooshimizu Gonai
Contents/schedule	10:00- 1) Slip surface survey 2) Physical test 3) Landslide cross section Mr. Noda 11:00- 4) Geophysical exploration 5) Rock fall survey 6) Debris flow survey Mr. Kasahara


Photo 6.3.6 Photo of landslide, debris flow and rock fall survey/analysis seminar (2)

f. Monitoring analysis

Table 6.3.7 Contents of monitoring analysis seminar

Date / Time	11 October 2011, 14:00-17:00
Place	JICA project office in GSE
Participant	<C/P> Demis Alamrem, Samiel Molla, Tekalegne Tesfaye, Habtam Eshete, Beruku Abel, Yewubnesh Bekele, Zulfa Abdurahman <JICA experts> Shoji Tsuchiyama, Mitsuya Enokida, Yoshimizu Gonai
Contents/ schedule	14:00- Monitoring survey 1)Monitoring a way 2)Monitoring installation 3)a question and other Mr. Tsuchiyama, Enokida, Gonai


Photo 6.3.7 Photo of monitoring analysis seminar

g. Early-warning system

Table 6.3.8 Contents of early-warning system seminar

Date / Time	13 October 2011, 14:00-17:00
Place	JICA project office in GSE
Participant	<C/P> Demis Alamrem, Samiel Molla, Tekalegne Tesfaye, Habtam Eshete <JICA experts> Shoji Tsuchiyama, Yoshimizu Gonai
Contents/ schedule	14:00- Early-warning system 1)Evacuation standard 2)general early-warning system 3)Early-warning system in Abay Gorge Mr. Tsuchiyama, Gonai


Photo 6.3.8 Photo of early-warning system seminar

h. Monitoring data organization (2)

Table 6.3.9 Contents of monitoring data organization seminar (1)

Date / Time	14,16 October 2011, 10:00-12:00,14:00-16:00
Place	JICA project office in GSE
Participant	<C/P> 14 October 2011, 14:00-16:00, Demis Alamrem, Habtam Eshete, 16 October 2011, 10:00-12:00, Samiel Molla, Beruku Abel 16 October 2011, 14:00-16:00, Tekalegne Tesfaye, Zulfa Abdurahman <JICA experts> Shoji Tsuchiyama
Contents/ schedule	Monitoring data control 1)Extensometer 2)Borehole extensometer 3)Borehole inclinometer 4)Automatic water level meter Mr. Tsuchiyama, Gonai


Photo 6.3.9 Photo of monitoring data organization seminar (1)

i. GIS, hydrological observation, soil parameter of stability analysis

Table 6.3.10 Contents of GIS, hydrological observation, soil parameter for analysis seminar

Date / Time	25 October 2011, 14:30-17:00
Place	JICA project office in GSE
Participant	<C/P> Tekaligne Tesfaye, Samuel Molla, Yewubnesh Bekele, Demis Alamirew, Habtamu Eshete, Biruk Abel, Debebe Kifle, Zulfa Abdurahman, Tewodros Alene(ERA) <JICA experts> Shigekazu Fujisawa, Yooshimizu Gonai, Mitsuya Enokida
Contents/schedule	14:30- 1) The use method of GIS 2) Analysis feature of GIS Mr. Gonai 15:30- 3) Interpretation of hydrological observation result 4) Prediction method of slope disaster Mr. Fujisawa 16:00- 5) stability analysis and the soil parameter Mr. Enokida


Photo 6.3.10 Photo of GIS, hydrological observation, soil parameter for analysis seminar

j. Stability analysis

Table 6.3.11 Contents of exercise of stability analysis

Date / Time	01 November 2011, 14:30-15:00
Place	JICA project office in GSE
Participant	<C/P> Tekaligne Tesfaye, Samuel Molla, Yewubnesh Bekele, Demis Alamirew, Habtamu Eshete <JICA experts> Mitsuya Enokida
Contents/schedule	14:30- 1) Approximate three-dimensional stability analysis 2) Exercise of stability analysis 3) Exercise of the reverse analysis Mr. Enokida

Photo 6.3.11 Photo of exercise of stability analysis

k. Integrated analysis

Table 6.3.12 Contents of Integrated analysis seminar

Date / Time	7 November 2011, 14:00-16:00
Place	JICA project office in GSE
Participant	<C/P> Demis Alamirew, Samuel Molla, Tekalegne Tesfaye, Habtam Eshete, Sisay Alemayehu, Erza Tadesse, Yewubnesh Bekele, Debebu Tekle <JICA experts> Masao Yamada, Satoru Tsukamoto, Kensuke Ichikawa
Contents/ schedule	14:00- Integrated analysis A question and other Mr. Yamada, Tsukamoto, Ichikawa

Photo 6.3.12 Photo of Integrated analysis seminar

6.3.3 On site training

On-site-type technical trainings have been conducted in the Project. The summary of the on-site-type technical trainings is shown in the following table. Some of them are described in this section.

Table 6.3.13 Summary of on-site-type technical trainings

Contents	Date	Place	C/P	JICA expert
Rockfall survey training Debris flow survey training	22,23 Jun., 2010	ST.30 -33	Leta Alemayehu, Tekaligne Tesfaye, Yewubnesh Bekele,	M. Enokida M. Noda Y. Kasahara
Monitoring data collection	7,8 Oct. 2010	Whole Abay Gorge	Solomon Gerra, Demis Alamrem, Leta Alemayehu, Tekalegne Tesfaye , Melkamu Tegegne, Beruku Abel, other ERA Member 5 persons	S. Tsuchiyama, M. Noda, Y. Yamamoto
Exchange knowledge and question/answer regarding to the drilling	9 Jun., 2011	L27	Leta Alemayehu, Bayu Wedajo, other drilling team members	T. Suzuki Y. Kasahara
Measurement method of monitoring devices using personal computer Estimation of monitoring data	14 Jun., 2011	L28	Ezra Tadesse, Habtam Eshete	M. Noda Y. Kasahara
Exchange knowledge and question/answer regarding to the monitoring	15 Jun., 2011	Kajima camp	Ezra Tadesse, Habtam Eshete	M. Noda Y. Kasahara
Installation method of water level meter	15 Jun., 2011	L27	Ezra Tadesse, Habtam Eshete	M. Noda Y. Kasahara
Landslide risk evaluation using sheet Check the deformation points, and mapping of the locations and conditions Monitoring method with devices	24 Jan., 2011	L/S 22	Tekaligne Tesfaye, Yewubnesh Bekele, Ezra Tadesse, Debebe Tekle	S. Tukamoto, M. Yamada, Y. Kasahara
Measurement method of cracks using pole and inclinometer Estimation of the landslide's movement direction and shape by crack direction	25 Jan., 2011	L/S00	Tekaligne Tesfaye, Yewubnesh Bekele, Ezra Tadesse, Debebe Tekle	S. Tukamoto, M. Yamada, Y. Kasahara
Cross-check of the movement and topographical map Mapping of the location of cracks	27 Jan., 2011	L/S 27,28	Tekaligne Tesfaye, Yewubnesh Bekele, Ezra Tadesse, Debebe Tekle	S. Tukamoto, M. Yamada, Y. Kasahara
Exchange knowledge and question/answer regarding to the landslide	28 Jan., 2011	Kajima camp	Tekaligne Tesfaye, Yewubnesh Bekele, Ezra Tadesse, Debebe Tekle	S. Tukamoto, M. Yamada, Y. Kasahara
Monitoring devices Data collection of the rain gauge and borehole extensometer	18 Feb., 2011	L/S 00	Getnet Mewa, Leta Alemayehu	S. Fujisawa, Y. Kasahara
Measurement method of monitoring devices preparation by personal computer Estimation of core logging	7 Jul, 2011	Kajima camp	Biruk Abel, Ezra Tadesse, Habtam Eshete	M. Noda
Field survey and integrated analysis	28,29,30 October 2011	Whole Abay Gorge	Samuel Molla, Demis Alamrew, Tekalegne Tesfaye, Habtamu Eshete	M. Yamada, S. Tsukamoto

a. Rockfall survey training

The slopes of the relevant rockfall hazard locations are very steep and high. For this reason, rockfall hazard locations were visually confirmed from the roadside in order to investigate the distribution of fallen rocks and slope conditions.

Tape measures and ranging poles were used to measure the diameter and dimensions of fallen rocks, which were recorded in a field notebook. A rangefinder (Nikon LASER 550A) was used in order to investigate the cross-sectional shapes of the slopes in rockfall hazardous areas.

Using a GPS device, coordinates of the hazard locations were obtained and marked on a topographic map.

Photo 6.3.13 Rockfall survey

Photo 6.3.14 Lecture of rockfall simulation

A lecture on rockfall simulation was held in the classroom using a program called "Rockfall Ver7.1" for transferring analysis methods as well as ways to select the parameters necessary for the simulation. Detailed analysis methods will be provided in the second phase.

b. Debris flow survey training

After selecting stream channels in large watersheds, stream bed gradients, cross-sectional shapes, and the thickness of unstable sediment were measured using measuring tapes, rangefinders, and ranging poles at multiple points along the stream. For every point, coordinates were obtained using a GPS device, and pictures were taken.

A video about debris flow disasters in Japan was shown in the classroom, and the difference between debris flow characteristics in Japan and that of the Abay Gorge was explained. How to select necessary parameters and analysis methods was also described during debris flow simulation. Detailed analysis methods will be provided in the second phase.

Photo 6.3.15 On-site survey

Photo 6.3.16 On-site survey of stream bed

c. Monitoring data collection training

On-site seminars on the monitoring devices were held from 7th to 9th October 2010. The main purpose of the seminars was to summarize the method of extracting data from the measuring devices (mainly inclinometer, extensometer, borehole-extensometer, water level indicator) into data logger. The participants of this seminar are as shown in the list below. ERA was also invited to this seminar to share experiences of the landslide survey methodology.

Table 6.3.14 Contents of monitoring data collection training on October 2010

Date / Time	7,8 October 2010
Place	Abay
Participant	<C/P> Solomon Gerra, Demis Alamrem, Leta Alemayehu, Tekalegne Tesfaye , Melkamu Tegegne, Beruku Abel Other ERA Member 5 persons <JICA experts> Shoji Tsuchiyama, Makito Noda, Yosuke Yamamoto
Contents/ schedule	7 October 2010 13:00- Monitoring a way 17:00 Closing 8 October 2010 09:00- Monitoring a way 14:00- observation drilling core 16:00- Closing Mr. Tsuchiyama, Noda, Yamamoto

Photo 6.3.17 Photo of monitoring data collection training on October 2010

d. Field survey and integrated analysis training

Table 6.3.15 Contents of field survey and integrated analysis training

Date / Time	28,29,30 October 2011
Place	Abay
Participant	<C/P> Samuel Molla, Demis Alamrew, Tekalegne Tesfaye, Habtamu Eshete <JICA experts> Masao YAMADA, Satoru TSUKAMOTO
Contents/ schedule	28 October 2011 9:00- 13:00 Addis Ababa-Abay movement 14:00- 17:00 L/S00, L/S05 area landslide survey 29 October 2011 9:00- 12:00 L/S22area landslide survey, KURAR village debris flow survey 13:30- 17:00 L/S27, L/S28, L/S10 area landslide survey 30 October 2011 9:00- 13:00 Abay movement -Addis Ababa

Photo 6.3.18 Photo of field survey and integrated analysis training

6.3.4 Training in Japan

The training in Japan has been conducted to ensure the technical transfer has been successfully operated through phase 1 and 2, and to experience and learn techniques at the sites and research institutes of several organizations. The training in Japan is scheduled from 18/June/2011 to 23/June/2011 and the content of the training is shown in Table 6.3.16. The summary of the training is as follows.

a. Summary of Training Course

Title of the course: Training on Landslide investigation and monitoring

Training period: 18/June/2011 - 8/July/2011

Trainee: 4

b. Outline of the Training

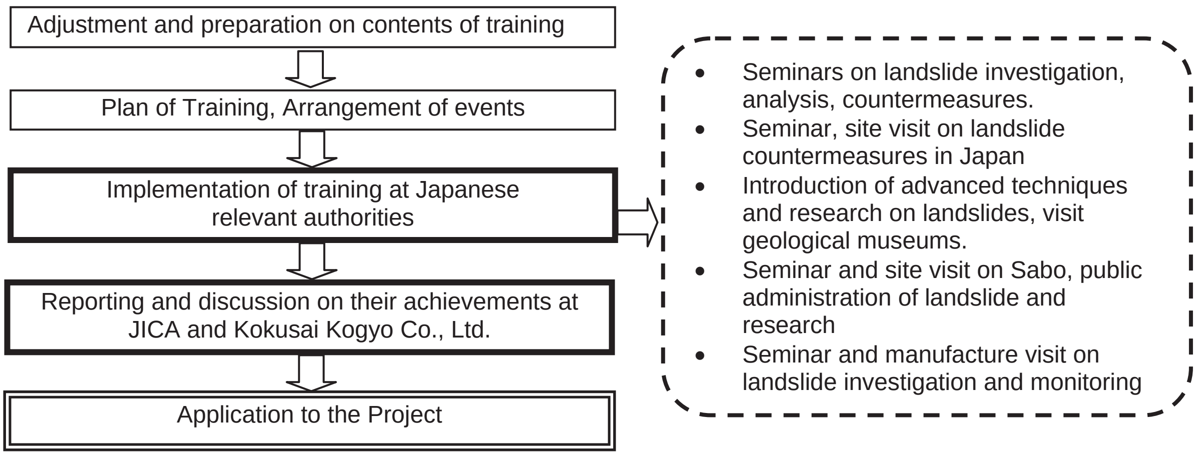


Figure 6.3.2 Outline of the training in Japan

Table 6.3.16 Schedule of training in Japan

No.	Date		Place/Transportation	Organization	Contents
1	18-Jun	Sat	Addis Ababa - Dubai		Emirates Airline EK724 19:35-00:45
2	19-Jun	Sun	Dubai - Narita - Tokyo		Emirates Airline EK315 2:50-17:35
3	20-Jun	Mon	Tokyo	JICA Kokusai Kogyo Co. Ltd.	Courtesy call Briefing meeting in KKC/ Welcome party
4	21-Jun	Tue	Saitama	Japan Conservation Engineers Co. Ltd.	Lecture of investigation/analysis for landslide in JCE Practical training for landslide
5	22-Jun	Wed	Fuchu, Tokyo	Kokusai Kogyo Co. Ltd.	Lecture of investigation/analysis for landslide in KKC Practical training for landslide
6	23-Jun	Thu	Tokyo → Takasaki	Tonegawa River/Sobo Office, Land, Infrastructure and Transportation Ministry	Field visit to Yuzurihara Landslide in Gunma Prefecture
7	24-Jun	Fri	Takasaki → Tokyo	Takasaki River/Road Office, Land, Infrastructure and Transportation Ministry	Field visit to landslide/rockfall/debris flow on National Road 17/18 in Gunma Prefecture
8	25-Jun	Sat	Tokyo		Holiday
9	26-Jun	Sun	Tokyo		Holiday
10	27-Jun	Mon	Tokyo Chiba	Raito Kogyo Co. Ltd.	Lecture of countermeasure s for landslide Field visit to countermeasure site for landslide
11	28-Jun	Tue	Tokyo → Shin Fuji Shin Fuji → Shizuoka	Fuji Sabo Office, Land, Infrastructure and Transportation Ministry	Field visit to Yui Landslide in Shizuoka Prefecture
12	29-Jun	Wed	Shizuoka → Hyogo	Asago Agriculture & Forestry Promotion Office, Hyogo Prefecture	Observation of Okubo Landslide
13	30-Jun	Thu	Hyogo → Kyoto	Asago Agriculture & Forestry Promotion Office, Hyogo Prefecture	Observation of Okubo Landslide
14	1-Jul	Fri	Kyoto	Research Center on Landslides, Disaster Prevention Research Institute, Kyoto University	Introduction of latest landslide research in Japan
15	2-Jul	Sat	Kyoto → Tokyo		Transportation
16	3-Jul	Sun	Tokyo		Holiday
17	4-Jul	Mon	Tokyo → Tsukuba	Landslide Team/ Geology Team, Public Works Research Institute OYO Chishitsu Co. Ltd.	Introduction of latest landslide research in Japan Visit to monitoring device factory in OYO
18	5-Jul	Tue	Tsukuba → Tokyo Tokyo	Geological Museum Kokusai Kogyo Co. Ltd.	Tour of National Geological Museum Meeting in KKC/ Farewell party
19	6-Jul	Wed	Tokyo	Japan International Corporation Center (JICE) JICA	Preparation of training report in JICE Evaluation meeting in JICA
20	7-Jul	Thu	Tokyo - Narita - Dubai		Emirates Airline EK319 21:40-4:35
21	8-Jul	Fri	Dubai - Addis Ababa		Emirates Airline EK723 8:25-11:30

c. Contents and Purpose of Training

The purpose of the training and its contents are tabulated in Table 6.3.17.

Table 6.3.17 Contents and purpose of training

No.	Major Title	Training Method	Purpose	Hrs	Major organizations as
1	・Seminar on landslide investigation, analysis and countermeasure ・Geohazards in Japan	Seminar	Considering application to the Project through the seminar on geohazards	6	・Japan Conservation Engineers Co. Ltd ・Kokusai Kogyo Co. Ltd.
2	・Seminar on landslide countermeasure ・Site visit on landslide countermeasure	Seminar Site visit	Understand the basics, theory and actual implementation as LGU and national project in Japan. Consideration of its application in Ethiopia	26	・Tonegawa River/Sobo Office, MILT ・Takasaki River/Road Office, MILT ・Raito Kogyo Co. Ltd. ・Fuji Sabo Office, MILT ・Asago Agriculture & Forestry Promotion Office, Hyogo Prefecture
3	・Introduction of advanced research on landslide ・Visit Geological Museum	Seminar Site visit	Understand the case study and analysis method of landslide in Japan and world. Gain knowledge and consideration of utilization of analysis equipment and soil testing machinery on landslide.	6	・Research Center on Landslides, Disaster Prevention Research Institute, Kyoto University
4	・Administration of landslide and Sabo, landslide research	Seminar	Gain the knowledge and consideration of application to the home country on administration on Sabo and landslide.	3	・Landslide Team/ Geology Team, Public Works Research Institute
5	・Site visit of the manufacturer of landslide monitoring devices and equipment	Seminar Site visit	Understand the mechanism and consider its application on monitoring devices and equipment.	3	・OYO Chishitsu Co. Ltd.

d. Summary of the training result

1. The manager of the Project of counterpart staff unfortunately could not attend the training due to illness. However, the trainees consisted of young geologists and geoscientists who are expected to be active in geohazard investigation in Ethiopia in future.

2. Trainees were eager to learn either at the seminar and site. They were enthusiastic to understand and learn the techniques on landslides as they made a lot of questions to the presenter even in the short time frame.

3. The preparation of the Japanese side was profound and reflected sincere to the visitors as foreigners. All presenters organized classroom seminars coupled with site visits of slope stability countermeasure construction sites..

4. The sessions always started with the Japanese side explaining the site conditions before visiting the actual site. This made it easier for the trainees to understand and grasp the overview of the site conditions. Japanese side arrangements were good enough for smooth implementation of the training.

5. At some of the organizations not all of the materials could be translated into English.

Throughout the training, both sides respected each others intentions and obligations. This made the training effective and helped it run smoothly. The satisfaction level of the trainees was high.

Throughout the training, either side respect each others intention and obligation. This made the training effective and smooth implementation. The satisfaction level of the trainee was high.

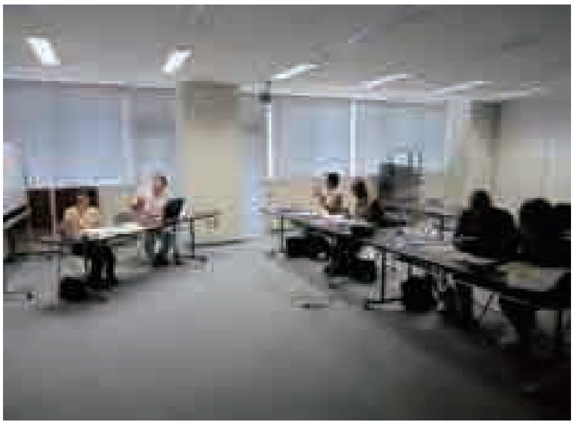


Photo 6.3.19 Presentation at MILT

Photo 6.3.20 Visit at hazard administration room

地すべり対策 学ぶ

来日のエチオピア研究員

Photo 6.3.21 Article of local newspaper reporting the training

6.4 Capacity assessment

6.4.1 Contents of Questionnaire

To understand the capacity of C/P for the landslide technology in the Project, capacity assessments (hereinafter referred to as CA) were conducted in April 2010, November 2010 and November 2011; which were assumed to be the technical level of the C/P at the beginning, after phase 1 and after phase 3 respectively. The CA was in the form of a questionnaire, and it was divided into two forms: one multiple-choice questions and the other comment/proposal format. This questionnaire is prepared to grasp the level of counterparts' understanding of investigation and analysis, significance of monitoring, application of analysis, and proceeding of the landslide project. Each questionnaire contains the following. The Question Form and its results are attached in the Appendix.

a. Multiple-choice questions

The multiple-choice questions are classified into the following specific five categories and each items for the category:

1) Project Implementation
- Purpose of the Project
- Flow of the Project implementation
- Flow of landslide survey
- Introduction of landslides in Japan
- Major activities in Phase 2

2) Geomorphological Survey
- Significance of geomorphological surveys for landslides
- Flow of geomorphological analysis and hazard mapping
- What are landslide "micro landforms"
- Introduction of type of landslide movement
- What is a landslide distribution map

3) Geological Survey
- Significance of geological surveys for landslides
- Flow of geological survey and analysis
- How to decide a main slip surface
- How to make geological cross sections
- Methodology and results of rockfall/debris flow surveys

4) Landslide Monitoring
- Significance of monitoring of landslides
- Introduction of monitoring devices
- Device installation
- How to analyze the monitoring data
- Relationship between monitoring results and landslide movement

5) Stability Analysis
- Significance of stability analysis of landslides
- Introduction of landslide mapping
- How to analyze landslide stability

Each question has five possible answers: 1=not understand, 2=difficult, 3=moderate, 4=understood, 5=well understood. The final results are compiled by the number, the lowest is 1 and highest is 5. Total maximum points in each category will be a score of 25 (15 only for Stability Analysis), which means that the person with this score has good knowledge.

b. Comment and Proposal

The “comment and proposal” question is to ask specific comments, opinions and proposals of the individual C/P regarding the Project and/or investigation/analysis of landslides. The question is in a free-writing format.

6.4.2 The Result of CA

Figure 6.4.1 shows the difference of their knowledge between the early stage and the final stage of the project. The CAs were conducted in April 2010, November 2010 and November 2011; which were assumed to be the technical level of the C/P at the beginning, after phase 1 and after phase 3 respectively. It is clear that the level of knowledge of the C/P have all advanced, however, this is not the case for engineers in every category. The technical transfer structure was targeted to make all the C/P the same level, but this attempt seems to have failed. It is difficult to update all engineers' skills evenly within the limited time frame, and moreover, the C/P teams' capacity was strengthened by the end. This fact will surely contribute to the future operation of the C/P team.

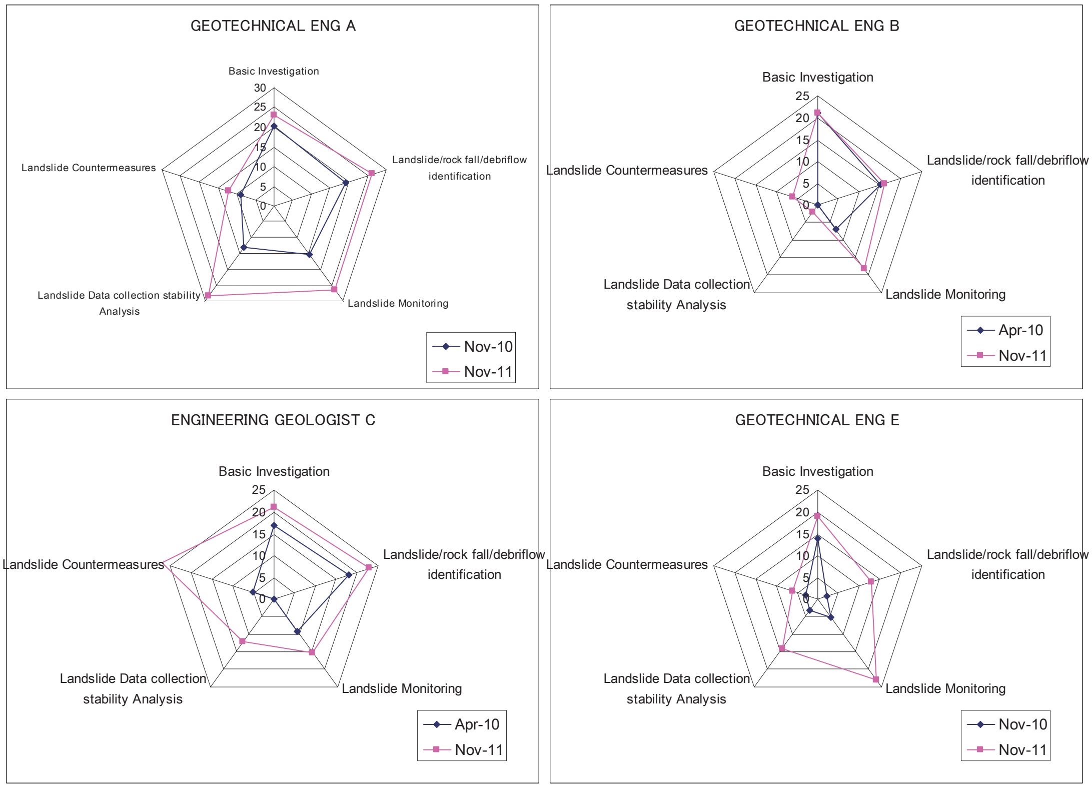


Figure 6.4.1 Penta-diagram of the Scores of C/P level by Category (1)

On the other hand, Figure 6.4.2 shows opposite result, namely no improvement from the start to the end of the project. Actually, C/P members are operating most of the landslide survey by their own in the phase 3, and it is clear that their skills developed during the Project. The figure may suggest that the technical level with which they initially viewed themselves was higher before they gained an understanding of landslide survey methods. However, after they learnt these new survey methods, they realized their skills were inadequate in this area.

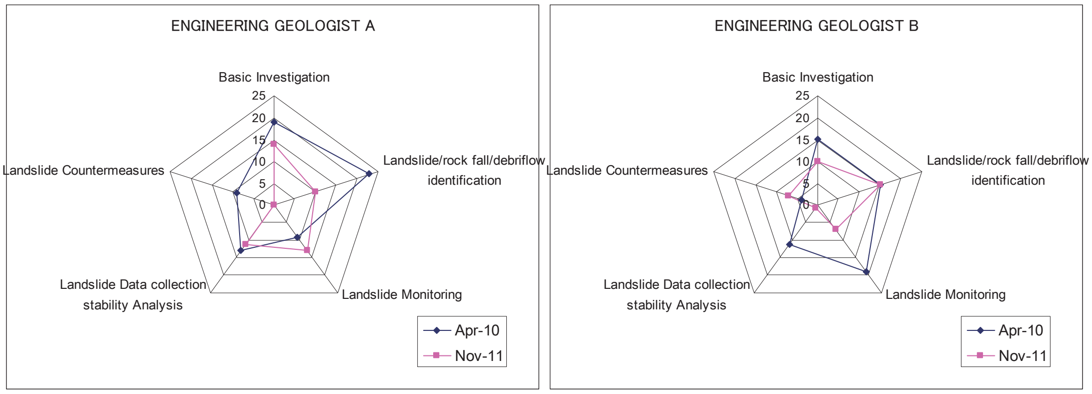


Figure 6.4.2 Penta Diagram of the Scores of C/P level by Category (2)

6.4.3 Collected Comments and proposals

The following data was summarized from comments and proposals in the questionnaire.

Table 6.4.1 Comments and proposals on the questionnaire

Comments and proposals
It would have a positive effect on what you are doing. Students from universities should be encouraged to come and work their projects with you for the knowledge transferring process.
For the problem in which the cause is human beings, why is advice on techniques to implement an action for the concerned organization not given.
If there are any landslide problems after the ones that are investigated, it is better if you consider that.
The presentations are appreciated as well as its concept. The fact that it was well organized, and accommodation and service too.
It will be good to add some coordinated field investigations in addition to monitoring work.
At the end of each phase of the project, a report will be produced by the consultant, therefore it was suggested that a brief summary of the report be distributed to the participants of the seminar.

6.5 PDM

6.5.1 Contents of initial PDM

PCM will be used for project management and monitoring, and the Project Design Matrix (hereinafter PDM) was discussed during the Inception Report discussion on April 2010. The PDM was approved by both parties and the PDM_1 took effect as of this meeting. Since then, no major changes have been made as the Project is achieving the Outputs in accordance with the Activities.

However, it should be noted that the Important Assumption of <Inputs> *"GSE can obtain sufficient budget to appropriately operate and maintain the equipment and facilities necessary for measurement work"* was not facilitated for the drilling works. This matter was discussed in the JCC, and was resolved in that meeting and discussions with concerned agencies.

Therefore, the PDM description will remain as is, but the delay (2.5 months) to the drilling works should be noted, and the other landslide measurement activities were delayed accordingly. This fact may affect the output of *4. The landslide characteristics due to seasonal change are identified*. The PDM_1 is presented on the following pages.

Table 6.5.1 PDM1

Duration: March 2010 to December 2011
Study area: Areas prone to landslides in the Abay Gorge along national road 3 between Goha Tsiyon and Dejen (40.45 km)
Counterpart organization: GSE; relevant organizations: ERA

Date made: April 6th, 2010

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Important Assumptions
<Overall Goal> ・ To figure out the mechanisms triggering landslides in the Abay Gorge along national road 3; and to mitigate human suffering and economic losses by implementing appropriate countermeasures.	・Hazard map of Ethiopia is made, sites are selected according to surveyed demand, budget application is approved, and other landslide sites are surveyed. ・Work together with ERA to propose countermeasures	・GSE work reports ・State of ERA countermeasure implementation	
<Project Purpose> ・ To clarify landslide mechanisms in the Abay Gorge ・ To assist GSE to acquire skills to analyze and investigate landslides	・Grasp the current situation and risk, investigate basic and inducing factors, and after developing the implementing organization's capacity, make a report on landslide mechanisms	・Content of landslide mechanisms report made after capacity development of implementing organization ・ERA can effectively plan countermeasures	・Operation and maintenance of observation equipment, and data acquisition is complete
<Outputs> 1 The Project implementing system is established 2 The situation of landslides is identified 3 The geomorphological and geological condition of landslides is identified 4 The landslide characteristics due to seasonal changes are identified 5 The landslide mechanisms are figured out 6 The survey and analysis of disasters other than landslides are conducted 7 The counterpart agencies become familiar with landslide survey and analysis work	1 Project implementing system is established so that it can be continued after the Project is completed 2 Detailed topographical map is made, and the distribution of large scale landslide geomorphology and the size of disasters is grasped through aerial photo interpretation 3 Survey plans for landslide blocks are established, and the geomorphology and geology of the surrounding area is grasped from the results of survey implementation 4 Observation is implemented, and ground/underground movement and groundwater level secular change is grasped. Further, standards—based on these observation results—are established on activation of the early-warning system in the event of a landslide. 5 Landslide mechanisms/factors are figured out through survey and observation results, and risk is evaluated 6 Risk of slope disasters besides landslides is grasped, various simulations undertaken, and danger zones mapped 7 OJT and training on landslide survey/analysis is held, and after basic survey/analysis capacity has been developed, an overall survey/analysis manual is put together systematically	・Project records ・Progress reports (annual) ・GSE work reports ・Results of C/P technical appraisals implemented up until the final evaluation	・C/P who acquired new techniques do not resign
<Activities> 1-1 Grasp the equipment and personnel situation of GSE 1-2 A system of project implementation is established in GSE 1-3 Monitoring equipment is installed at sites of landslide occurrence 2-1 Topographic analysis is undertaken using aerial photography and photo interpretation to make a landslide map 2-2 Prioritize danger zones and make a hazard map 2-3 Implement hydrological survey 2-4 Develop a database of analysis results using GIS 3-1 Implement geomorphological/geological reconnaissance 3-2 Prepare a landslide survey plan 3-3 Survey geomorphology by geographical survey 3-4 Implement drilling geological survey 3-5 Implement drilling core physical/chemical tests 3-6 Implement geophysical exploration 4-1 Observe ground movement 4-2 Survey main slip surface 4-3 Implement groundwater level monitoring 4-4 Implement precipitation monitoring 4-5 Establish early-warning system 5-1 Identify landslide scale (plane/vertical) and its micro-landform units 5-2 Investigate basic factors of landslides 5-3 Investigate landslide inducing factors 5-4 Analyze stability of landslide slopes 5-5 Classify susceptibility of landslide blocks 6-1 Survey/analyze rockfalls 6-2 Survey/analyze debris flows 7-1 Create manual on landslide survey/analysis 7-2 Hold field training and OJT on landslide survey/analysis	**<Inputs>** **Japanese Side** 1. Study Team: Team leader; geomorphological analysis 1/hazard map; topographic survey; geomorphological analysis 2; GIS/database; geological survey/analysis 1; geological survey/analysis 2; hydrological survey/analysis; geophysical exploration/analysis; landslide monitoring/early-warning system; landslide stability analysis; landslide integrated analysis; drilling techniques; rockfall/debris flow survey/analysis 2. Equipment 3. Training in Japan **Ethiopia Side** 1. Counterpart assignment 2. Administrative work 3. Facilities for the implementation of the Project (office for the study team, and other fixtures and furniture to perform their duties) 4. Local costs (C/P employees' field work expenses, wages/daily allowance and training participation costs, utility costs, customs costs, equipment transportation, storage and installation costs, and equipment and facility operation and maintenance costs), however, the Japanese side is to bear the cost of GSE employee training in Japan 5. Other local costs necessary to implement Project activities 6. Data and information necessary for project implementation 7. Coordination with other relevant organizations on aerial photography by GSE		・GSE can obtain sufficient budget to appropriately operate and maintain the equipment and facilities necessary for measurement work ・Advice and support from relevant organizations can be obtained **<Preconditions>** ・This Project is approved by the Ethiopian government

6.5.2 Review of Achievements on PDM

In accordance with the PDM, the review of effectiveness of technical transfer will be described. Through out the project period, the technical transfer was smoothly implemented and the C/P was cooperative. Their major achievement on the output in PDM is shown in Table 6.5.2 and the results of activities are compiled in the Table 6.5.3.

Table 6.5.2 Achievements of Technical Transfer

No	Items of Technical Transfer	Score	Achievement
1	Establishment of the project implementing system	A	The project was started the counterpart members without knowledge of landslide monitoring and analysis. Therefore, the establishment of mechanism to conduct the monitoring and analysis was considered. The activity was conducted on OJT bases which the C/P joins each expert's investigations and other activities during the project period. The step by step approach was applied. Phase I: OJT, Phase II: Analysis, Phase III: C/P's responsible activities. Therefore, C/P could systematically earn the basic knowledge to handle all activities at Phase III.
2	Landslide identification	A	The areal photograph was not taken due to the bad weather during the Phase I. The landslide identification was mostly done by using satellite imaginary. C/P earn the necessary skills to identify the landslide.
3	Identification of features of geomorphologic and geological on landslide	A	Not only geomorphologic and geological survey on landslide, geophysical sounding, and installation of monitoring device has been also conducted with C/P. They are able to conduct installation and monitoring of the landslide movement as well as surface/subsurface survey.
4	The seasonal change on landslide characteristic will be recognized	A	By using the monitoring devices such as extensometer, inclinometer, bore hole inclinometer, water level gauge and rain gauge, C/P are able to recognize the not only seasonal change but also day by day difference of the landslide.
5	The landslide mechanism has been identified	B	In relation with the monitoring result of rainfall and the movement of landslide, the preliminary idea of the mechanism was understood. However, it requires longer time period to recognize mechanism of landslide.
6	The survey and analysis of disasters other than landslides are conducted	B	Rock fall and debris flow survey and analysis were also conducted during this period. But the measures and analysis was mainly focused on the landslide.
7	The counterpart agencies become familiar with landslide survey and analysis work	A	During the project period, C/P earned the skills of landslide survey, monitoring and analysis. Moreover, joint effort with Ethiopia Road Authorities (ERA) was fully supported the drilling activities and shared the experience of the project.

(A: Successfully transferred, B: Fully transferred but need some additional effort in the future, C: Technical transfer was failed and their understanding is poor)

Table 6.5.3 Results of activities

PROJECT OUTLINE	INDICATORS	RESULT
<Overall Goal> • To figure out the mechanisms triggering landslides in the Abay Gorge along national road 3; and to mitigate human suffering and economic losses by implementing appropriate countermeasures.	• Work together with ERA to propose countermeasures • Hazard map of Ethiopia is made, sites are selected according to surveyed demand, budget application is approved, and other landslide sites are surveyed.	The appropriate countermeasure will be implemented in the near future and mitigate human suffering and economic losses can be achieved
<Project Purpose> • To clarify landslide mechanisms in the Abay Gorge • To assist GSE to acquire skills to analyze and investigate landslides	Grasp the current situation and risk, investigate basic and inducing factors, and after developing the implementing organization's capacity, make a report on landslide mechanisms	• The landslide mechanisms were identified • Landslide investigation skills of GSE has been transferred
<Outputs> 1 The Project implementing system is established 2 The situation of landslides is identified 3 The geomorphological and geological condition of landslides is identified 4 The landslide characteristics due to seasonal changes are identified 5 The landslide mechanisms are figured out 6 The survey and analysis of disasters other than landslides are conducted 7 The counterpart agencies become familiar with landslide survey and analysis work	1 Project implementing system is established so that it can be continued after the Project is completed 2 Detailed topographical map is made, and the distribution of large scale landslide geomorphology and the size of disasters is grasped through aerial photo interpretation 3 Survey plans for landslide blocks are established, and the geomorphology and geology of the surrounding area is grasped from the results of survey implementation 4 Observation is implemented and ground/underground movement and groundwater level secular change is grasped. Further, standards—based on these observation results—are established on activation of the early-warning system in the event of a landslide. 5 Landslide mechanisms/factors are figured out through survey and observation results, and risk is evaluated 6 Risk of slope disasters besides landslides is grasped, various simulations undertaken, and danger zones mapped 7 OJT and training on landslide survey/analysis is held, and after basic survey/analysis capacity has been developed, an overall survey/analysis manual is put together systematically	1 Project implementing system is established 2 Detailed topographical map is made, and aerial photo interpretation was transferred 3 Survey plans for landslide blocks are established, and the survey was implemented for technical transfer to C/P 4 Installation and monitoring of landslide monitoring devices are properly transferred to C/P. Basic Idea of establishment on activation of the early-warning system has been introduced. 5 Landslide mechanisms/factors are figured out through survey and observation results, and risk were evaluated 6 Landslide risk map and danger zones were identified. Various simulations on landslide, rock fall and debris flow are undertaken. 7 OJT and training on landslide survey/analysis is held, and an overall survey/analysis manual is put together
<Activities> As same as PDM above.	**＜Inputs＞** **Japanese Side** Experts, Equipment, Training in Japan **Ethiopia Side** 1 Counterpart assignment 2 Administrative work 3 Facilities for the implementation of the Project 4 Local costs 5 Other local costs necessary to implement Project activities 6 Data and information necessary for project implementation 7 Coordination with other relevant organizations on aerial photography by GSE	Activities are performed properly to achieve the goal **But the budget for drilling was not prepared by GSE as indicated in Important Assumption.** Finally it was agreed that GSE will secure the budget for fiscal year 2010/2012 so that the monitoring activities are conducted through rainy season which was necessary for the assumption of landslide measure

6.6 JCC

The JCC was held 5 times in the Project, twice during the phase 1, once during the phase 2 and twice during phase 3. The initial JCC was held to explain the role of the JCC followed by the explanation of outline of the Project to the concerned organizations and agencies. The second JCC was to further the understanding of GSE and JICA regarding budgetary issues rose in the Project. The third JCC was to discuss the budget of drilling operation in 2011 and its burden sharing, and the drilling plan for phase 2. The fourth JCC was to report the contents of ITR and to discuss the activities. The fifth JCC was to wrap up the entire Project. The contents of the JCC are summarized as follows. For more detailed results, see attached Appendix.

Table 6.6.1 Summary of JCC1

Item	Summary
Time and Date	16 April 2010, AM 9:00 – 11:00
Place	GSE Conference room
Contents	Project outline and role Expected role of ERA in the Project The proposal of Joint Task Force The members of JCC Counterpart assignment per specialties Procurement of equipment and machinery
Participants	GSE: Mr. Masresha G/Selassie (Chief Geologist), Dr Getnet Mewa (Head, Geohazard Investigation Core Process) ERA: Mr. Haddis Tesfaye (Manager, Network Management Division) JICA Ethiopia Office: Mr. Makoto Shinkawa (Senior Representative), Ms Momoko Suzuki (Representative) JICA Study Team: Mr. Kensuke Ichikawa (Team leader), Mr. Shigekazu Fujisawa (Hydrological Survey/Analysis), Mr. Takeshi Kuwano (Geological Survey/Analysis 1)

Table 6.6.2 Summary of JCC2

Item	Summary
Time and Date	1 July 2010, PM 2:00 – 4:00
Place	GSE Conference room
Contents	1. Clarification of JICA’s basic technical cooperation concept 1) Budget and burden sharing 2) Reporting system of the Japanese technical cooperation project to MoFED 3) Drilling Program 2. Current Project Status 1) Assistance required during drilling operations 2) Provision of site depot
Participants	GSE: Mr. Masresha G/Selassie (Chief Geologist), Dr Getnet Mewa (Head, Geohazard Investigation Core Process), Mr. Assefa Zerihum (Head, Planning, Monitoring & Evaluation Process), Mr. Solomon Gerra (Engineering Geologist), Mr. Demis Alamirew (Hydro-Geologist), Mr. Letta Alemayehu (Engineering Geologist), Ms Zufra Abdurahman (Engineering Geologist) ERA: Mr. Haddis Tesfaye (Manager, Network Management Division) MoFED: Ms Asnakech Teferra (Senior Expert) JICA Ethiopia Office: Mr. Makoto Shinkawa (Senior Representative), Ms Momoko Suzuki (Representative) JICA Study Team: Mr. Kensuke Ichikawa (Team leader), Mr. Takashi Suzuki (Drilling Specialist), Mr. Takeshi Kuwano (Geological Survey/Analysis 1)

Table 6.6.3 Summary of JCC3

Item	Summary
Time and Date	3 December 2010, PM 2:00 – 4:00
Place	GSE Conference room
Contents	1. The Purpose of JCC 3 (PR1 & Outstanding Issues for Phase 2 & 3) 2. PR1 and outline of the Phase 1 activities 3. Recent issue of the project 1) Plan for the drilling on phase 1 & 2 2) Budget of drilling operation in 2011 3) Burden sharing of stake holders 4. Discussion on the issues about drilling plan for next phase
Participants	GSE: Mr. Masresha G/Selassie (Chief Geologist), Mr. Assefa Zerihum (Head, Planning, Monitoring & Evaluation Process), Mr. Yiheyis Amdebrahan (Head, Drilling S.C.), Mr. Solomon Gerra (Engineering Geologist), Mr. Letta Alemayehu (Engineering Geologist), Ms Yewubnesh Bekele (Geologist) ERA: Mr. Haddis Tesfaye (Manager, Network Management Division), Mr. Takeshi Hara (JICA Expert for ERA) MoFED: Mr. Ibrahim Worku (Expert) JICA Ethiopia Office: Mr. Atsushi Nakagawa (Representative) JICA Study Team: Mr. Kensuke Ichikawa (Team leader), Mr. Takeshi Kuwano (Geological Survey/Analysis 1)

Table 6.6.4 Summary of JCC4

Item	Summary
Time and Date	10 May 2011, PM 3:30 – 5:00
Place	GSE Conference room
Contents	1. The Purpose of JCC 4 (ITR & Outstanding Issues for Phase 2 & 3) 2. ITR and outline of the Phase 2 & 3 activities 3 Activities of phase 3 1) Plan for the drilling on phase 3 2) Joint effort request for ERA on drilling activities 3) Plan of operation on drilling activities 4. Discussion on the issues about the role of stake holders
Participants	GSE: Mr. Hundle Melka (Chief Geologist), Dr Getnet Mewa (Head, Geohazard Investigation Core Process), Mr. Assefa Zerihum (Head, Planning, Monitoring & Evaluation Process), Mr. Bayu Wedaj (Drilling Engineer, Drilling S.C.) ERA: Mr. Alemayehu Ayele (Leader, Highway Research Team), Mr. Takeshi Hara (JICA Expert for ERA) JICA Ethiopia Office: Mr. Atsushi Nakagawa (Representative) JICA Study Team: Mr. Kensuke Ichikawa (Team leader), Mr. Satoru Tsukamoto (Geomorphologic Analysis 1/Hazard Map, Mr. Shigekatsu Fujisawa (Hydrological Survey/Analysis, Landslide Stability Analysis), Mr. Takashi Suzuki (Drilling Techniques), Mr. Yoji Kasahara (Geophysical Exploration)

Table 6.6.5 Summary of JCC5

Item	Summary
Time and Date	25 November 2011, PM 9:00 – 12:00
Place	GSE Conference room
Contents	1. Activities of project up to date 2. Submission of final draft report 3. Wrap up of the entire project 1) Summary of the project 2) Major achievements from the project 3) Outstanding issues 4. Discussion on the above issues 1) Delay of the equipment 2) Supply of drilling equipment, exploration device and related data 3) Delay in the completion of the project 4) Collaboration with ERA 5) Future projects on GSE with JICA 6) Conclusion of the project
Participants	GSE: Mr. Masresha G/Selassie (Director General), Mr. Hunde Melka (Chief Geologist), Mr. Assefa Zerihun (Head, Planning, Monitoring & Evaluation Process), Mr. Leta Alemayehu (Engineering Geologist), Mr. Samuel Molla (Engineering Geologist), Mr. Taddesse Lemma (Senior Geophysict), Mr. Sisay Alemayehu (Geophysict), Ms. Zulfa Abdurahman (Engineering Geologist), Mr. Habtamu Eshetu (Geologist) ERA: Ms. Abeba Berhanu (Acting lead Engineer) JICA Ethiopia Office: Mr. Atsushi Nakagawa (Representative) JICA Study Team: Mr. Kensuke Ichikawa (Team leader), Mr. Takeshi Kuwano (Geological Survey/ Analysis 1), Mr. Mitsuya Enokida (Geomorphological Analysis 2), Mr. Masao Yamada (Landslide Integrated Analysis), Ms. Yerom Moges (Assistant of JICA Study Team)

6.7 Biweekly Meeting

Biweekly meeting was initially planned so that each party gains an understanding of the other's activities for convenience, as well as to hold discussions on technical issues during the site and in-house activities. To date, the meeting has been held four times until June, and since that time, the major activities became on-site technical transfer.

This meeting is valuable for both the Study Team and C/P to exchange technical issues and to improve communication with each other..

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